Observing Ocean-Atmosphere Interaction Processes using VTOL UAVs

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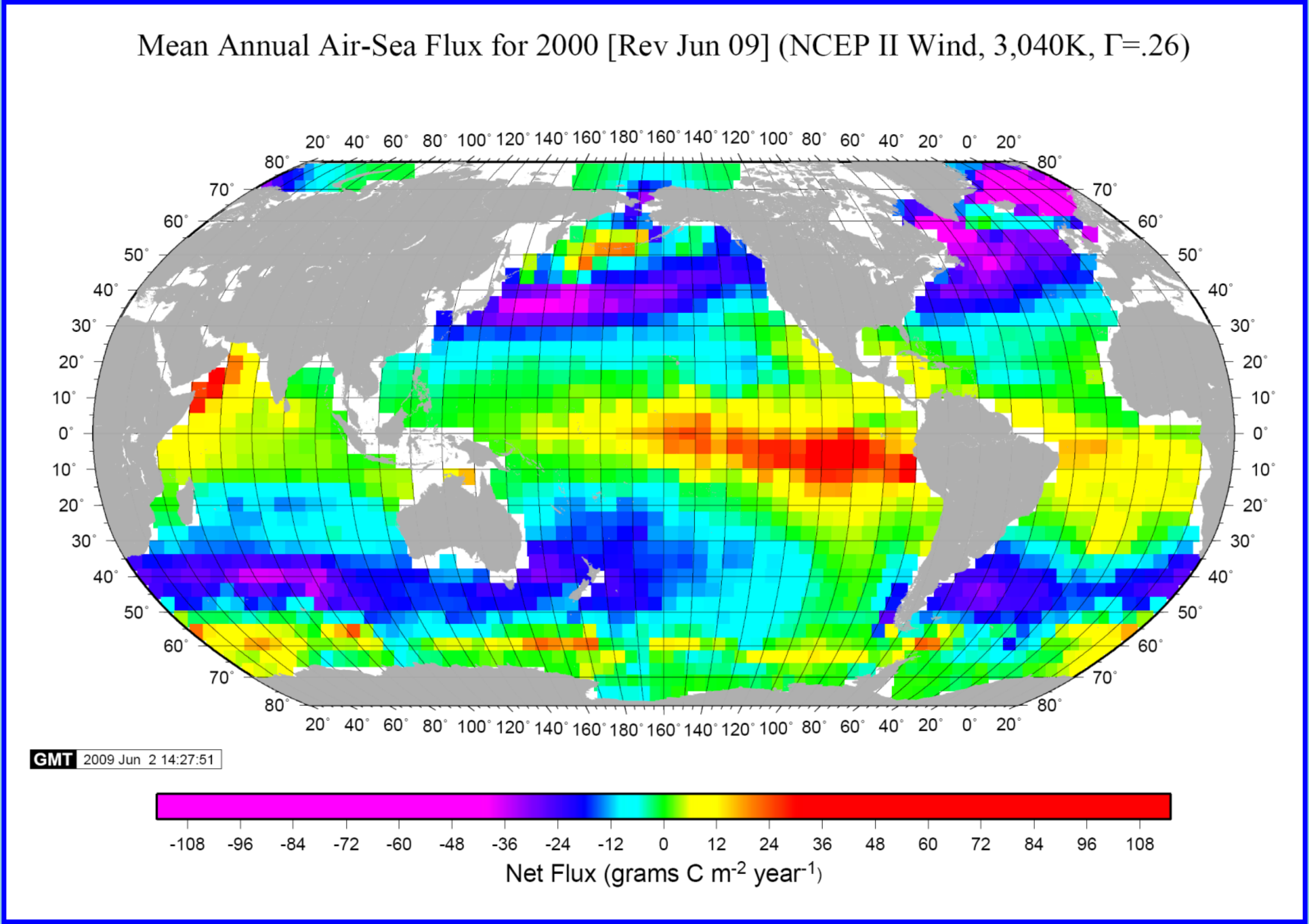
Acknowledgment to NASA UAS Program, NSF Polar Programs, the Moore Foundation, and Schmidt Ocean Institute.

2018 Marine UAS Winter School, FEUP, Porto, Lisbon January 16, 2018

Global Flux of CO_2

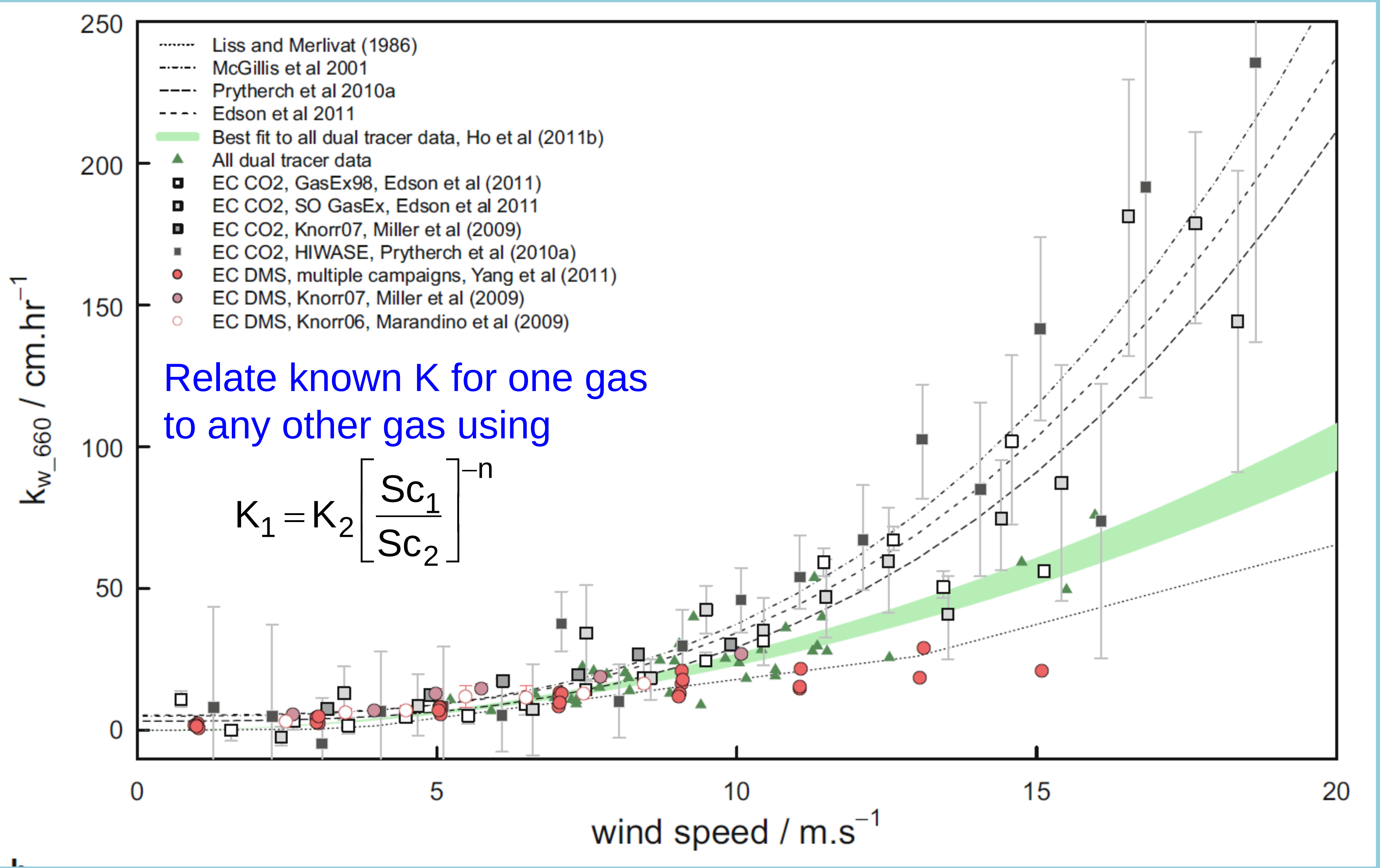


The flux of gas is the product of the gas transfer velocity and the concentration difference between atmosphere and the ocean

$$F = K\Delta c = Ks\left(pCO_{2a} - pCO_{2w}\right)$$

Takahashi et al., 2009

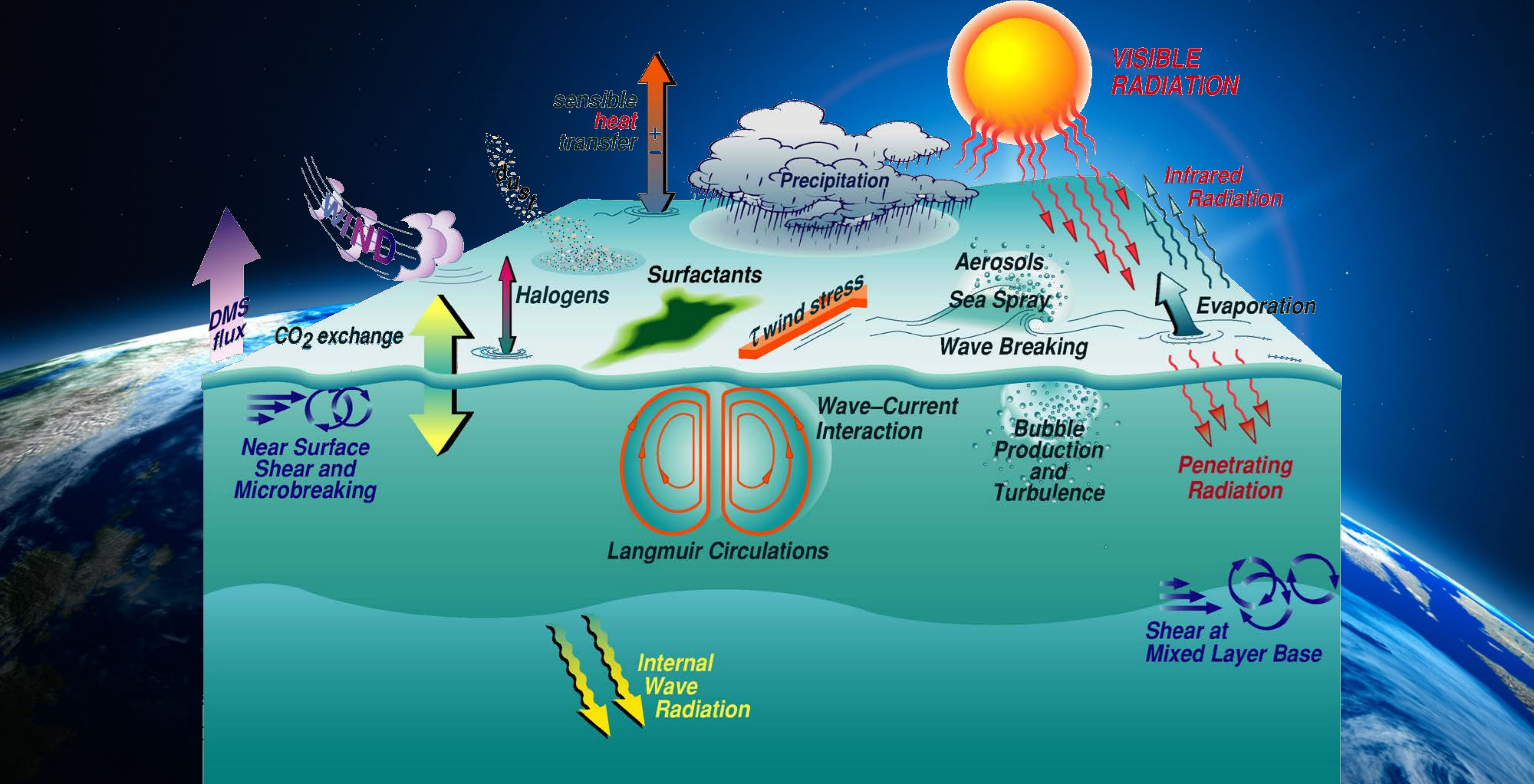
Transfer Velocity vs. Wind Speed



Relate known K for one gas to any other gas using

$$K_1 = K_2\left[\frac{Sc_1}{Sc_2}\right]^{-n}$$

Air-Sea Interaction Processes



Turbulence Scaling of Gas Transfer

Fick's Law $$F = D\frac{\partial C}{\partial z} = \frac{D}{\delta_D}\left(C_w - \alpha C_a\right) = K\left(C_w - \alpha C_a\right)$$

$$K = \frac{D}{\delta_D}$$

Boundary Layer Scaling

Batchelor [1959] (Melville [1996]);
Brumley and Jirka [1987,1988]

$$\delta_D \propto \left(\frac{\nu D^2}{\varepsilon}\right)^{1/4}$$

Batchelor Length Scale – turbulent microscale for a passive scalar

TKE Dissipation Rate

$$\boxed{K \propto (\varepsilon\nu)^{1/4}\, Sc^{-1/2}}$$

Wavy Turbulent Films: Banerjee et al. [1968]
Surface Renewal: Lamont and Scott [1970]
Breaking Waves: Kitaigorodskii [1984]

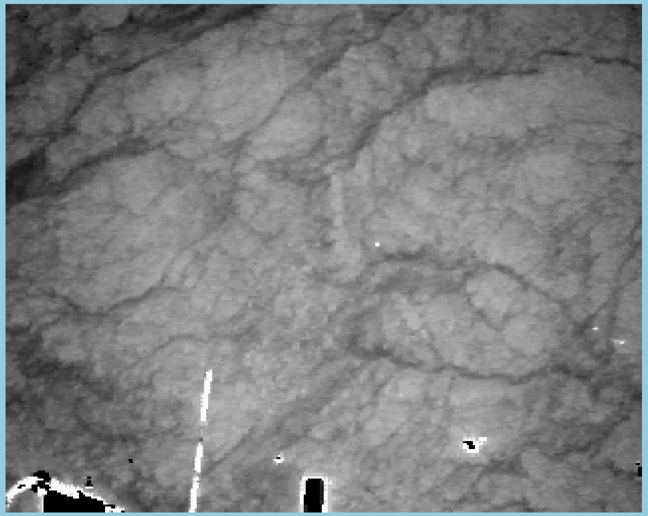
- Kinetic energy cascades from larger scales down to smaller scales.
- Turbulent kinetic energy dissipation rate describes the rate at which this process occurs

Experiments Estimated Turbulent Scales:
- Asher and Pankow [1986]
- Dickey et al. [1984]
- recently others

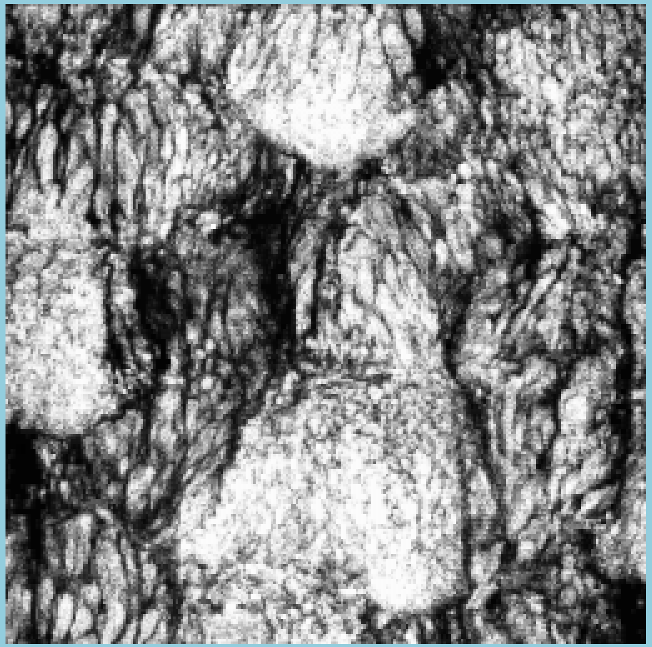
Summary for Moderate Wind Speeds and Coastal Systems

Movies from SPIP

Tides

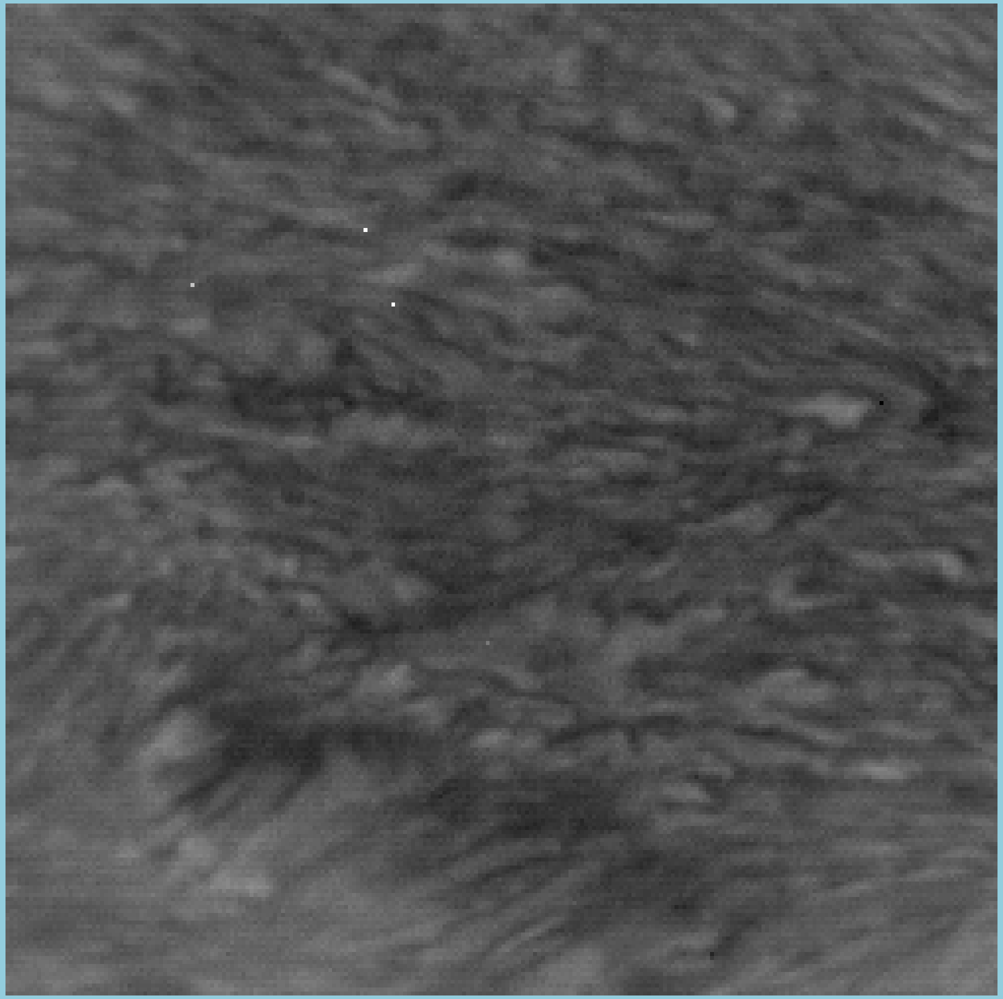


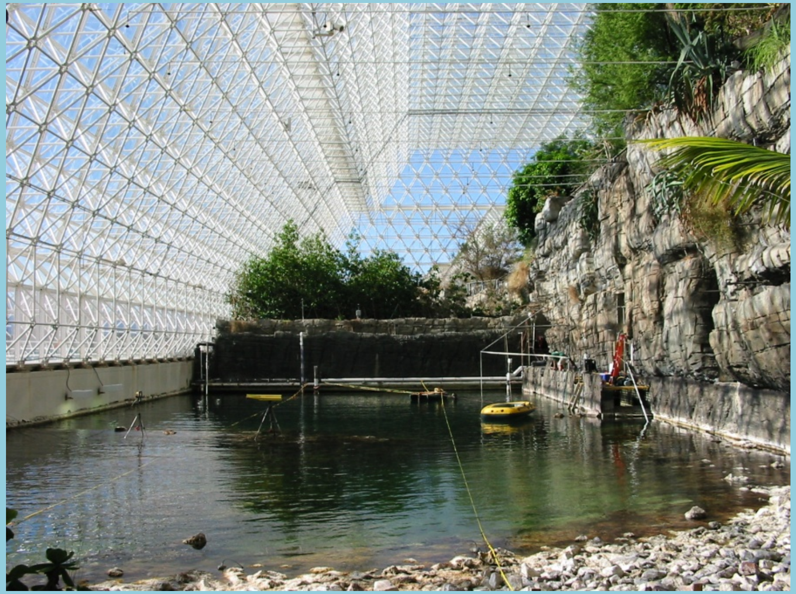
Wind

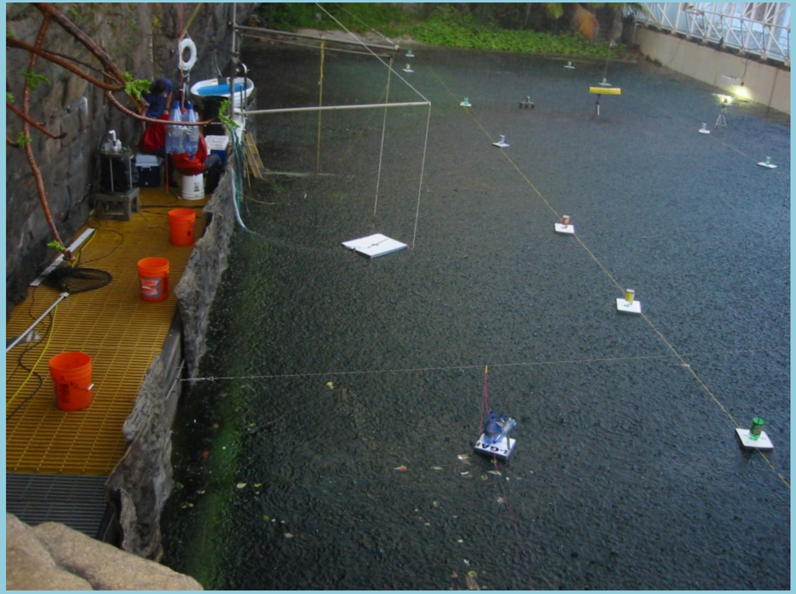


- Infrared imagery shows the spatial and temporal variability that affects air-water exchange.
- Estuarine transfer velocities at low wind speeds are shown to track the turbulence generated during the tidal cycle.
- Complex interplay between tidal- and wind-driven exchange.

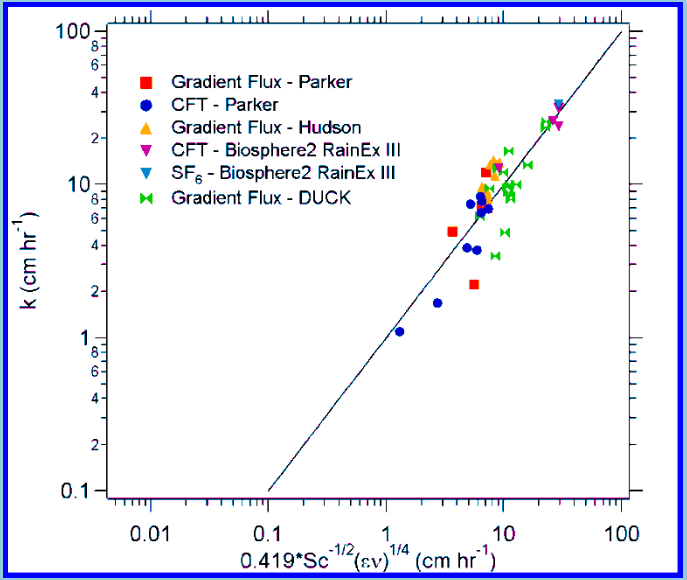
Infrared Imagery of Rain

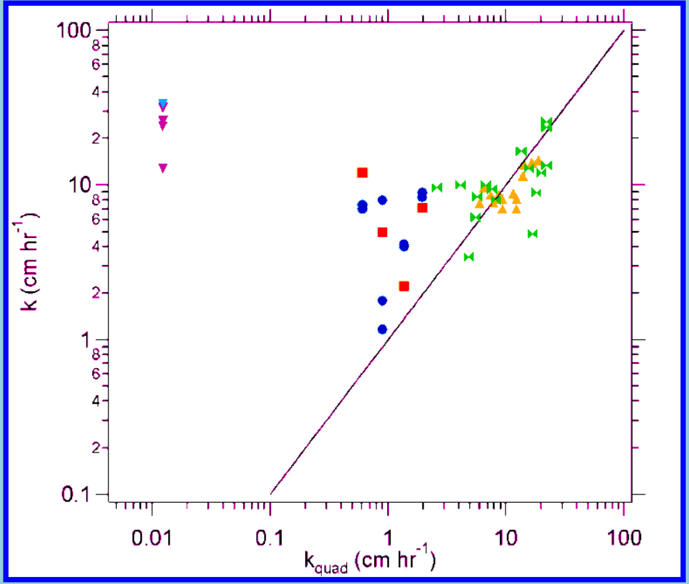






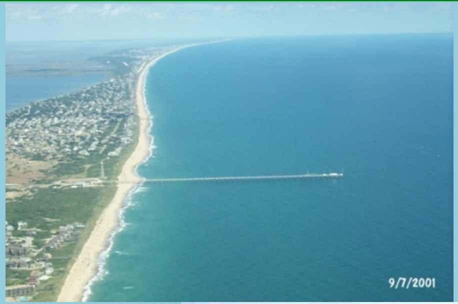
Turbulent Mixing Control on Gas Transfer





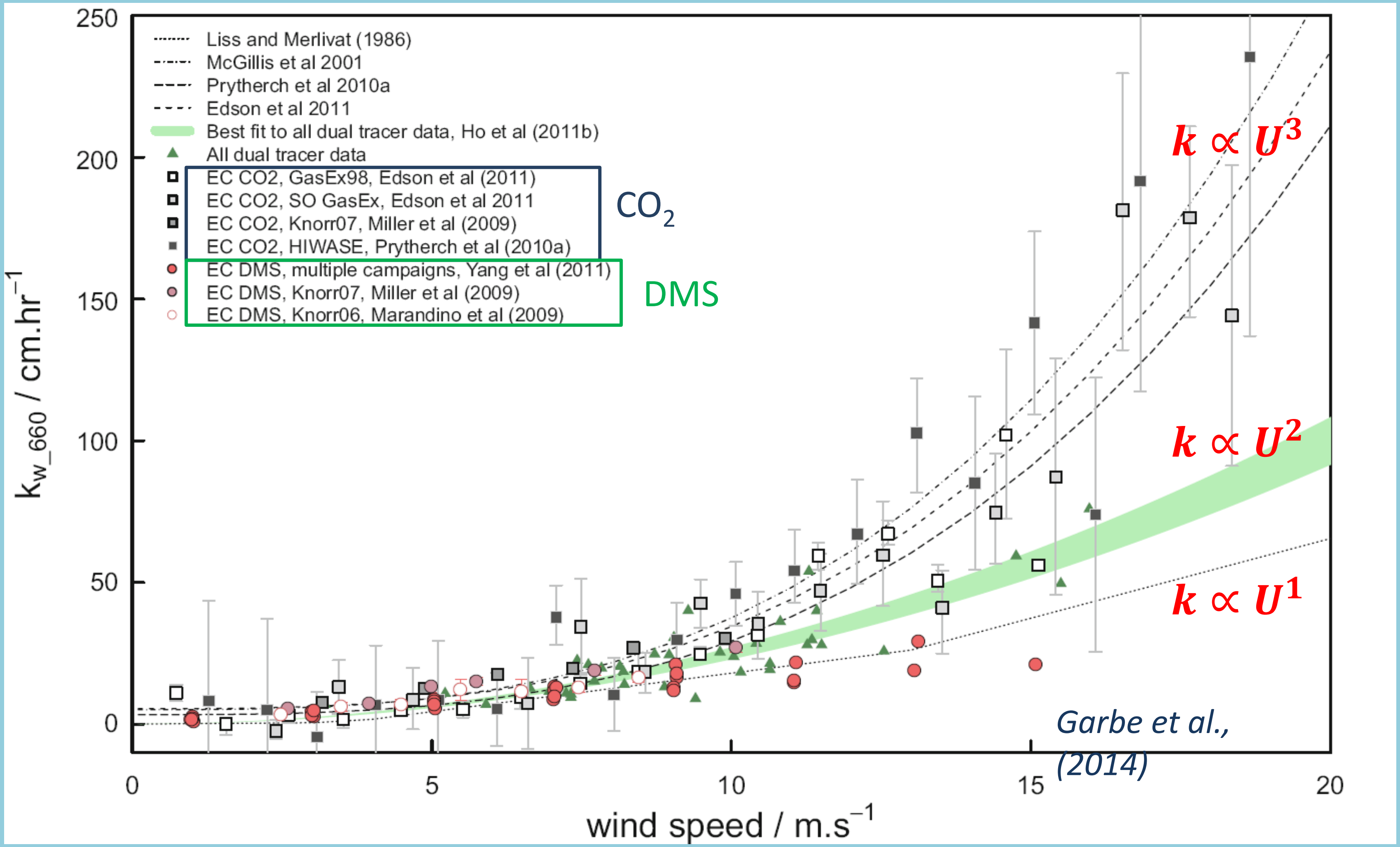
- Variety of environmental forcing and processes (Wind, Currents, Rain, Waves, Breaking, Surfactants, Fetch)
- Wind speed does not capture the process variability of air-water exchange.
- Turbulent dissipation shows promise for estimating K in a variety of dynamic systems.
  - Near-surface is critical
- Implications for:
  - Modeling
  - Satellite Estimation
  - Coastal/Regional Importance

Wanninkhof [1992] quadratic relationship



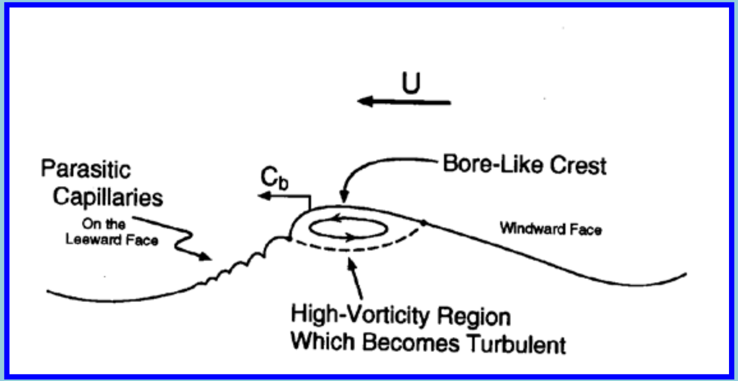
Zappa, C. J., W. R. McGillis, P. A. Raymond, J. B. Edson, E. J. Hintsa, H. J. Zemmelink, J. W. H. Dacey, and D. T. Ho (2007), Environmental turbulent mixing controls on the air-water gas exchange in marine and aquatic systems, *Geophys. Res. Lett., 34(L10601), doi:10.1029/ 2006GL028790.*

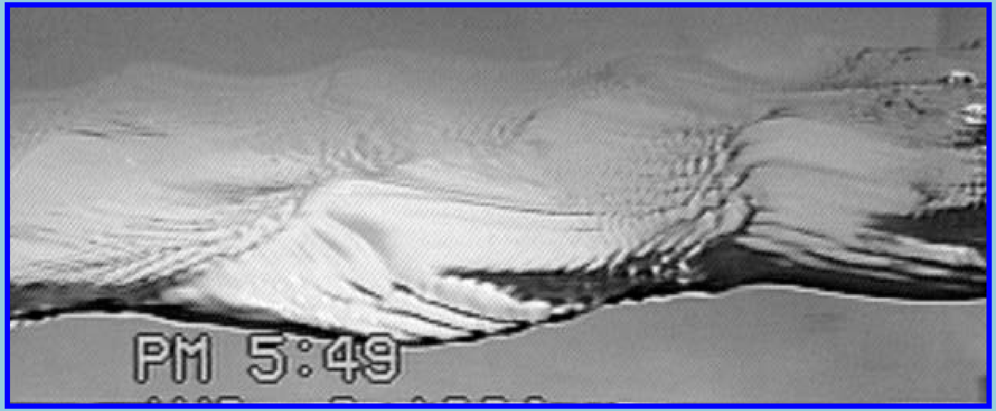
Recall – the *k* conundrum



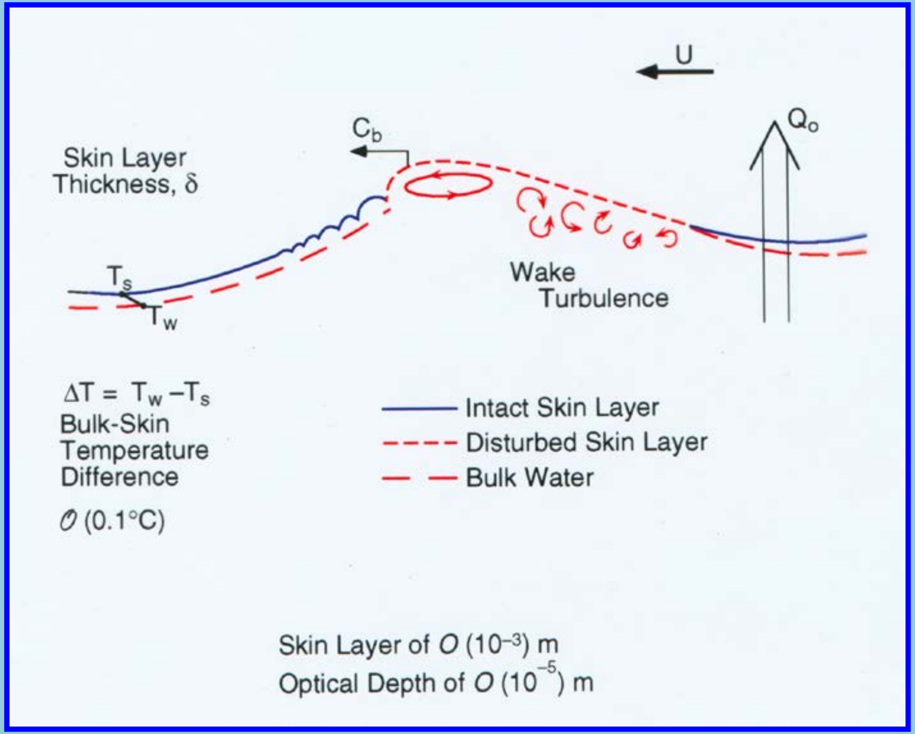
Characterizing Microscale Wave Breaking

Incipient breaking of small scale waves that do not entrain air.





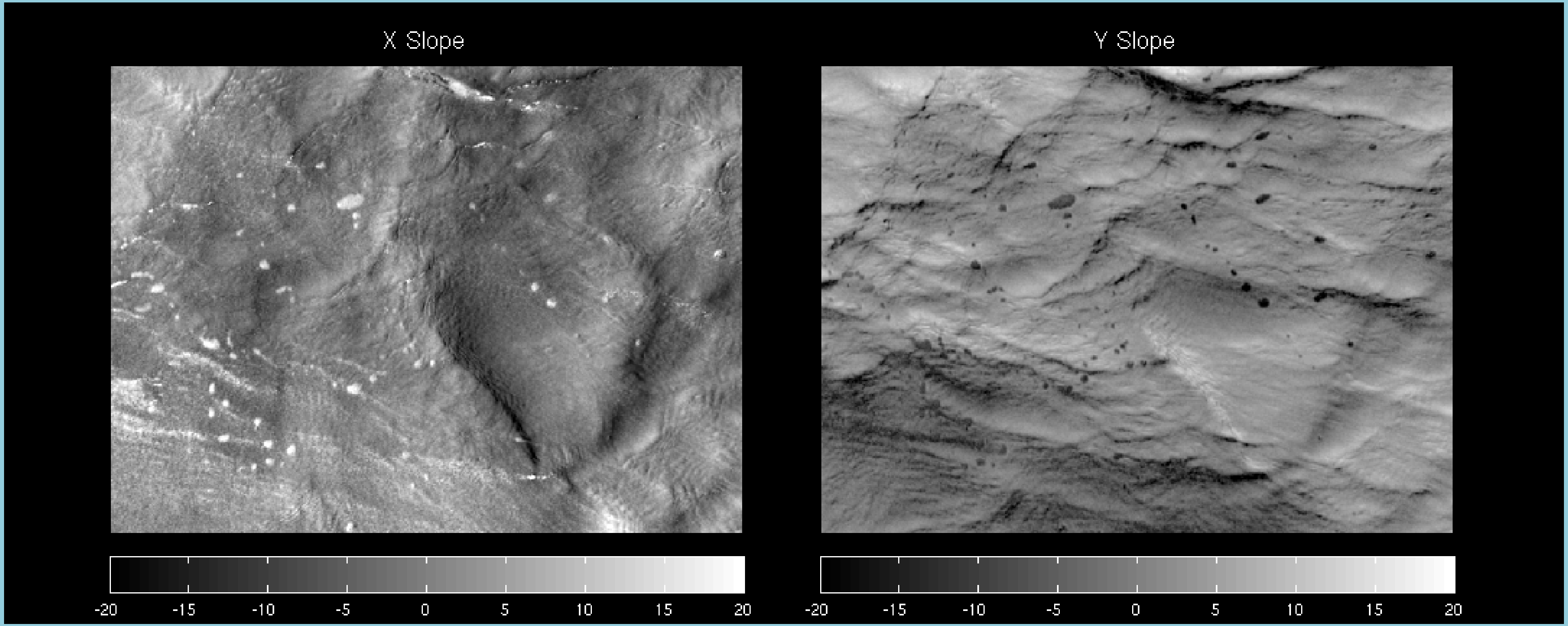
L ~ *O* (0.1-1m)
a ~ *O* (0.01m)



Skin-layer disruption by microbreaking events produces thermal signatures that can be detected and quantified using IR imagery.

<u>Hypothesis</u>: Microscale wave breaking is the underlying physical process that controls gas transfer at low to moderate wind speeds.

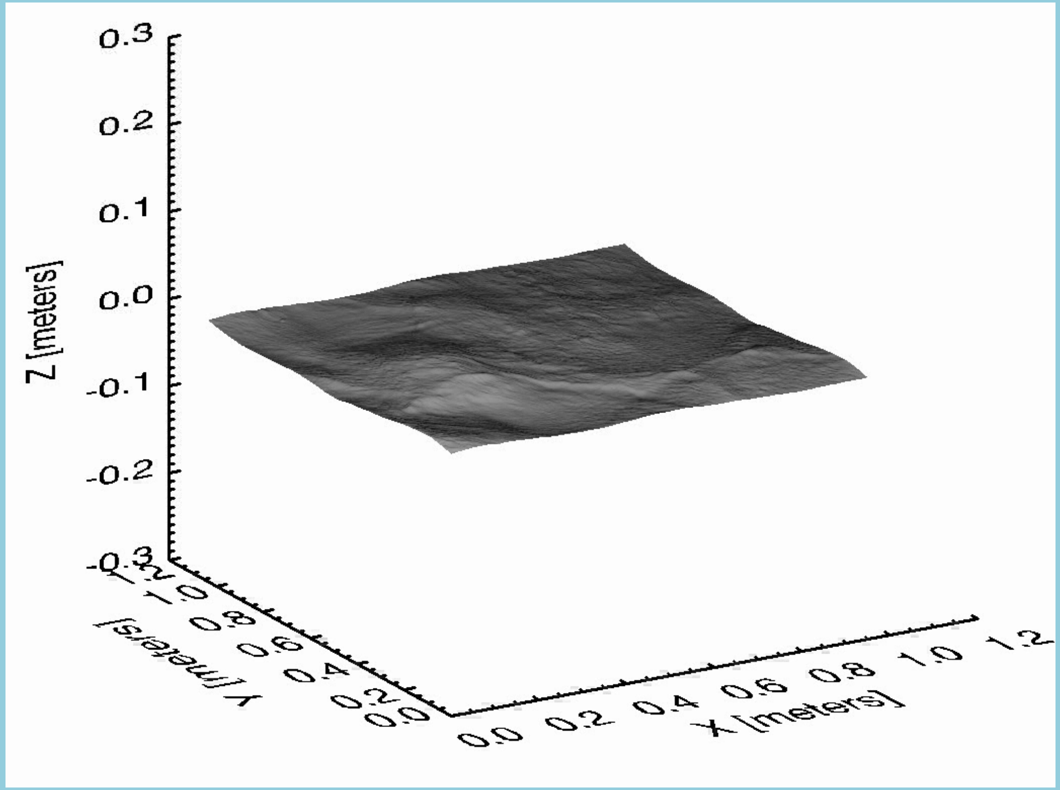
Polarimeter Slope Topography



Y- and X-component surface slope arrays computed from polarimetric images taken with the polarimeter during the RaDyO experiment in the Santa Barbara Channel from R/P Flip Sept. 2008. The scale shows the relationship between slope and grayscale.

Image scale is 1 m by 1 m. U_{10} = 9.2 m s^{-1}

Wave Height from Polarimeter Topography



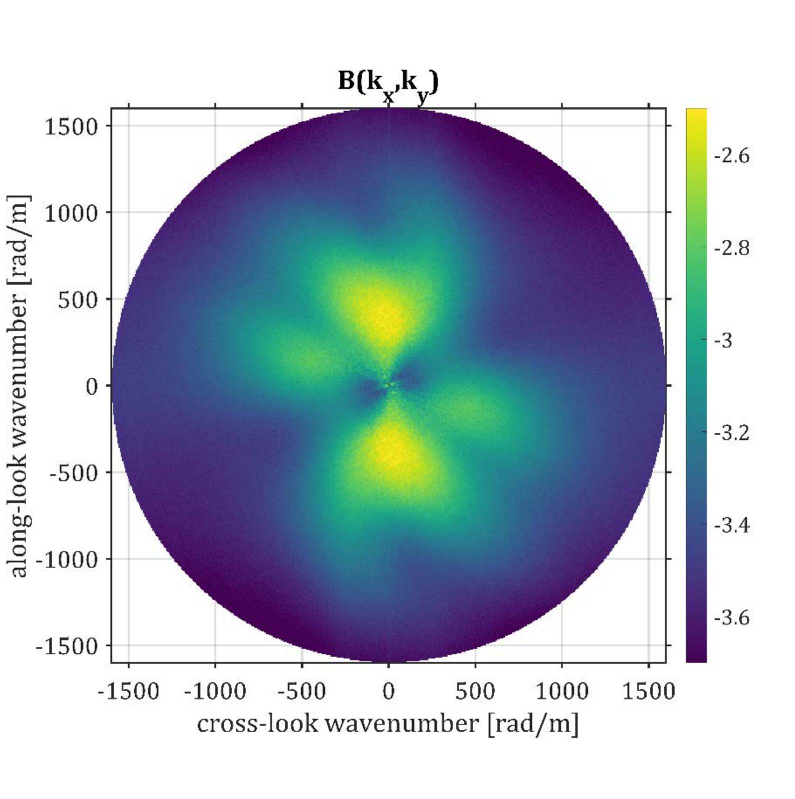
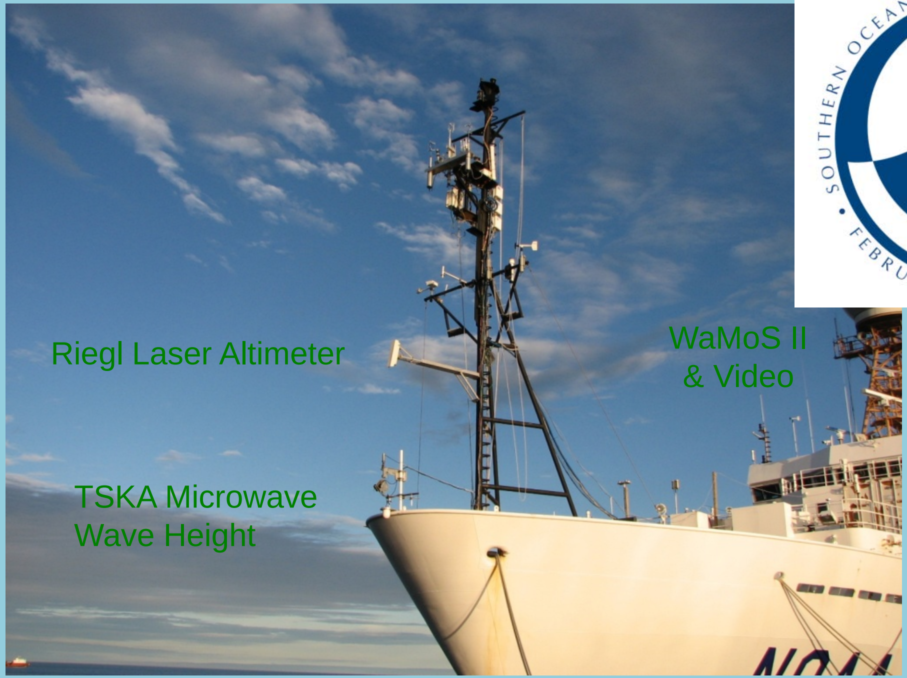
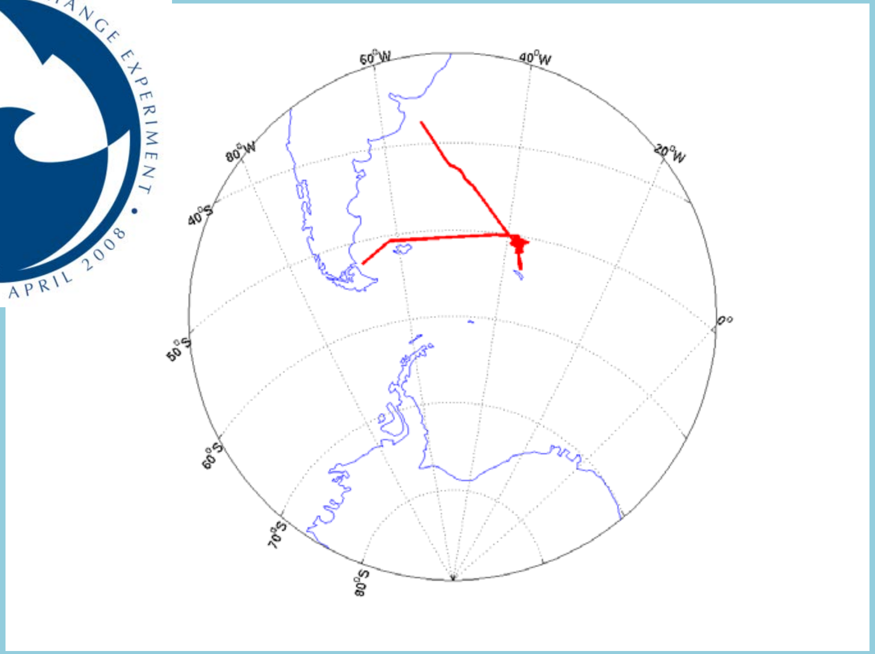


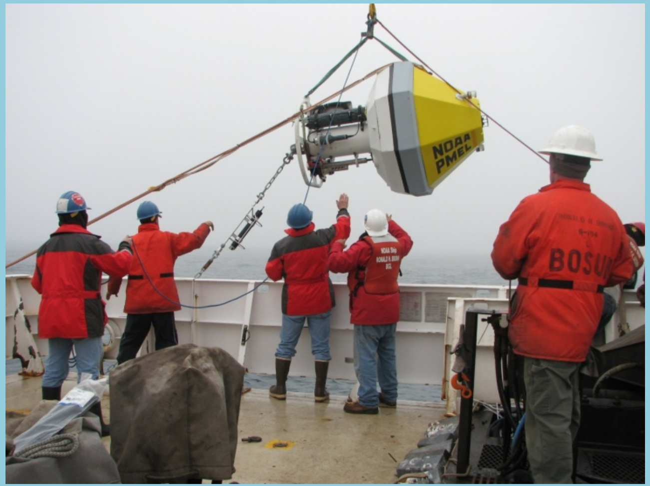
Image scale is 1 m by 1 m. U_{10} = 9.2 m s^{-1}

Southern Ocean GasEx Experiment 2008

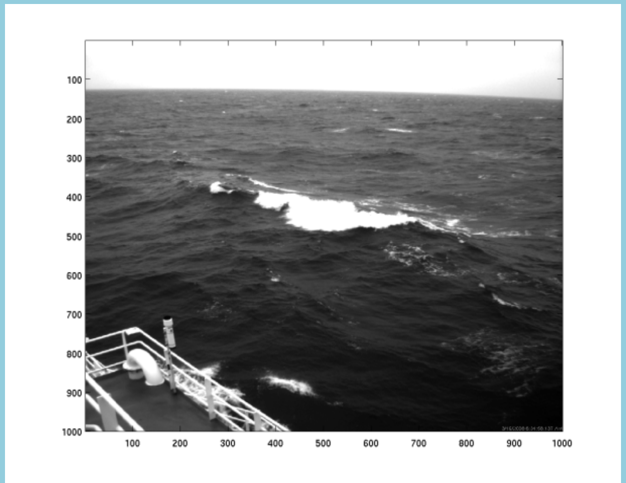




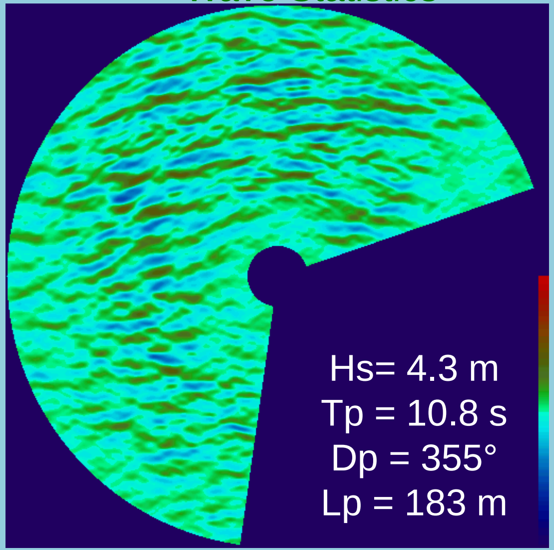
Near-Surface Turbulence



Whitecapping



Wave Statistics



Southern Ocean Movie

The High Wind speed Gas Exchange Study (HiWinGS)

Where: Labrador Sea – Nuuk to WHOI

When: Oct 9 – Nov 14 2013

LDEO Measurements: Ship-Based **Visible Imaging**

20 Hz frame rate (Continuous during daylight)

1000 x 1000 pixels ~100 m x 100 m

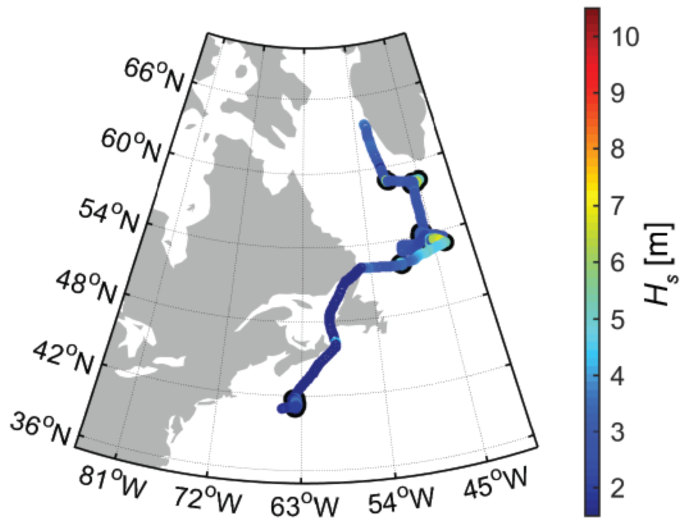
IMU mounted to each camera allows for motion correction

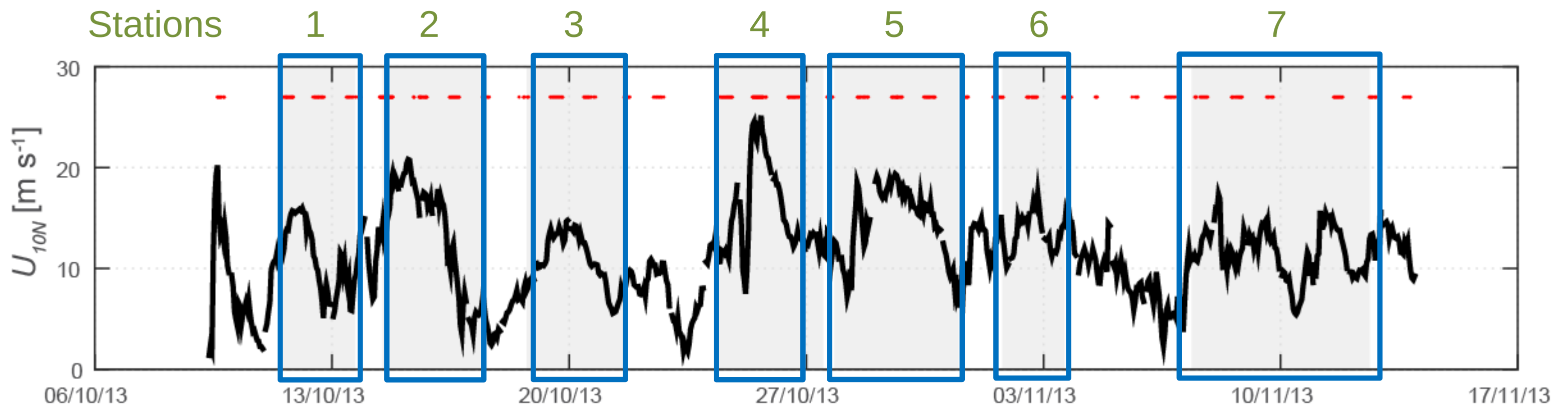
Additional Measurements:

Wave field: Riegl Altimeter (continuous till station 4)

Wave Rider buoy (on station)

Meteorological and chemical fluxes (CO_2, DMS…)



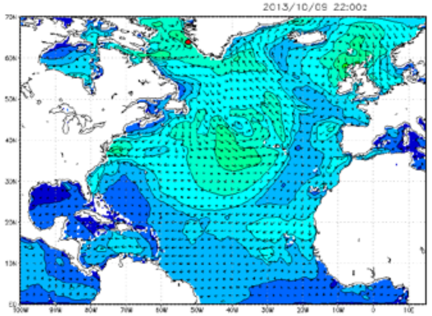


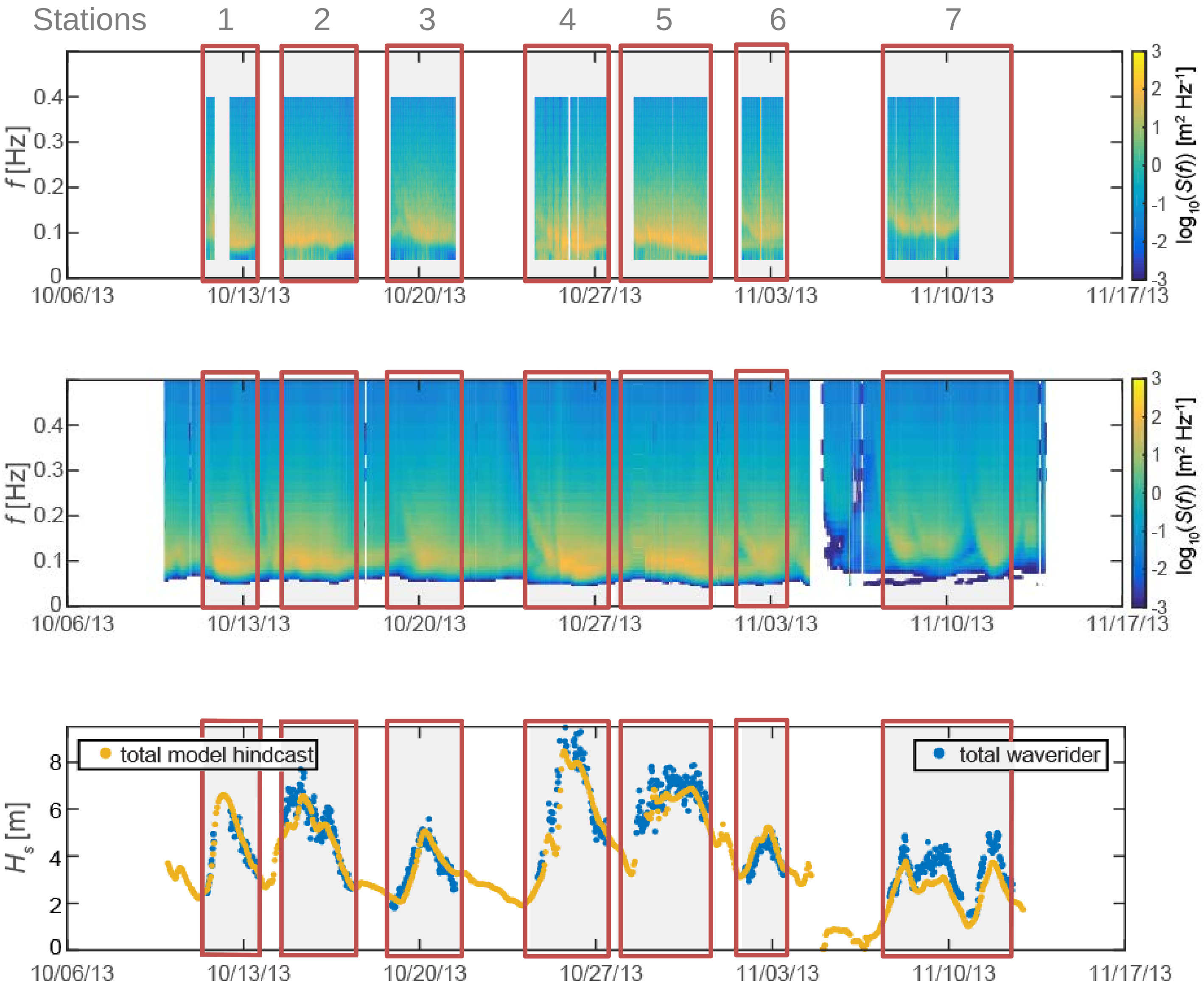
U_{10N} > 15 m s^{-1} for 25% of the time & 48 hrs with U_{10N} > 20 m s^{-1} !

Wave Field Data

Wave Rider Buoy

WAVEWATCH-III



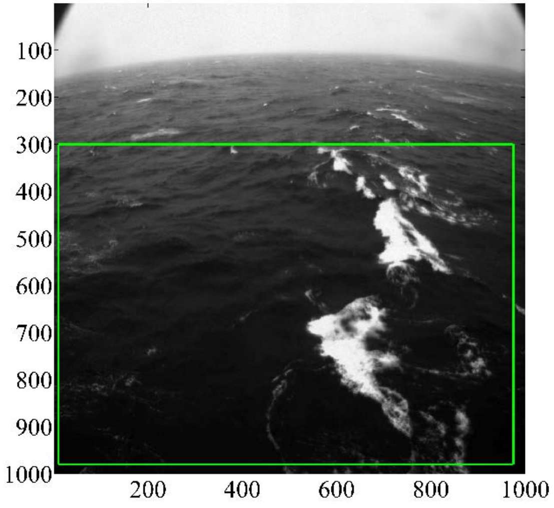


$$H_s = 4\left[\int E(f)df\right]^{1/2}$$

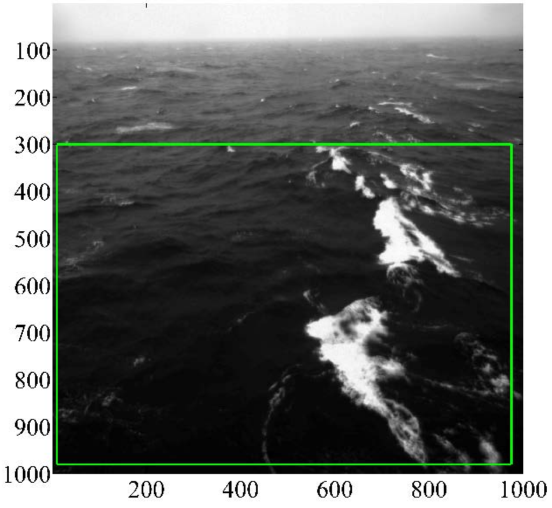
More in *Brooks et al., (2017)*

Whitecap coverage - image analysis now

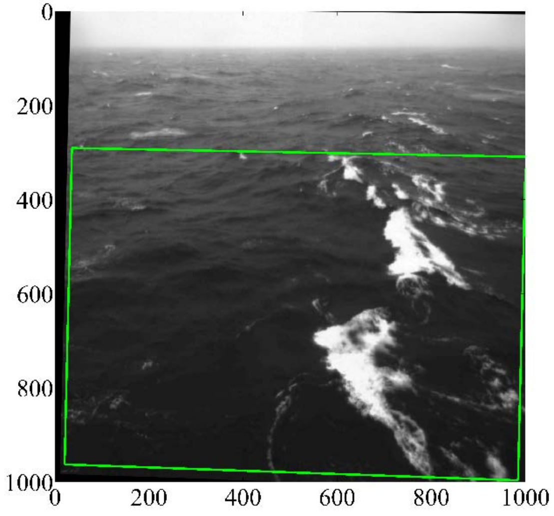
Raw image



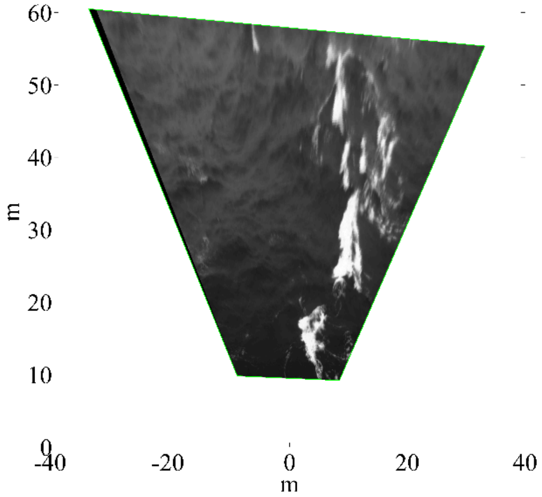
Lens distortion correction



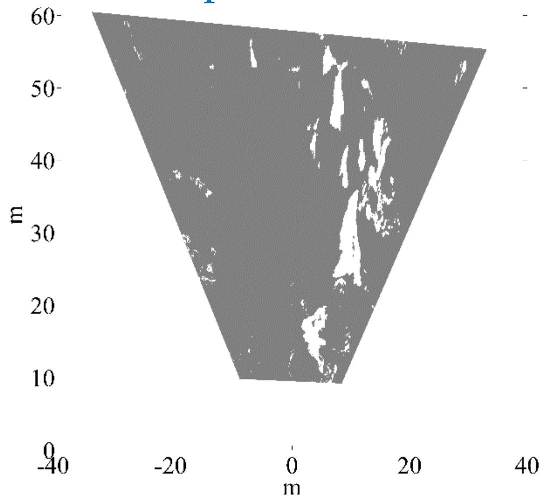
Roll and yaw correction

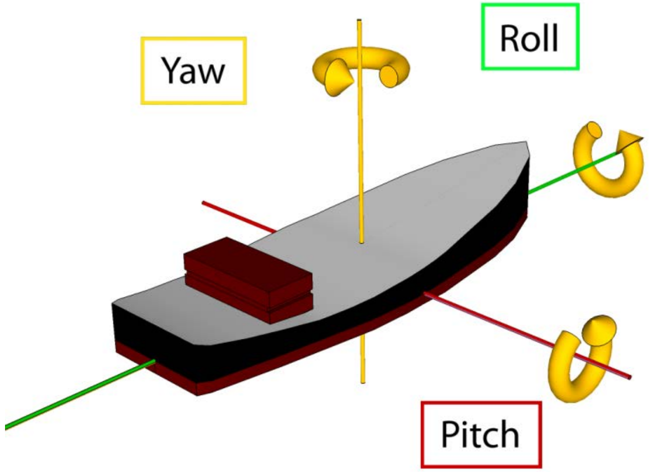


Projection



Whitecap detection





Brumer et al., (2017). On the dependence of whitecap coverage on environmental parameters observed during HiWinGS and SO GasEx. JPO

Bubble-Mediated Gas Transfer

Asher and Wanninkhof [1998] **Direct Whitecapping**

$$K = \left(47U_{10} + W_C\left(1.5\times10^5 - 47U_{10}\right)\right)Sc^{-1/2} + W_C\left(-\frac{37}{\alpha} + 10{,}440\alpha^{-0.41}Sc^{-0.24}\right)$$

Wind-Generated Turbulence

Whitecap-Generated Turbulence

Injection

Non-Equilibrating Bubbles

Solubility-Dependent Bubble-Mediated Exchange

Parameterization based on extensive laboratory measurements

Overall parameterization based on Memery and Merlivat [1985].
Non-equilibrating bubbles functional form based on Keeling[1993].

Woolf [2005] **Sea State Dependent Wave Breaking**

$$K = K_O + K_B$$

$$K = 1.57\times10^{-4}u_*(600/Sc)^{1/2} + 2\times10^{-5}R_{Hw}$$

$$R_H = u_* H_s/\nu.$$

Based on the Wave Reynolds # argument of Zhao and Toba [2003]

Others based on the Breaking Wave Parameter of Zhao and Toba [2001], Toba and Koga [1986]

$$R_B = u_*^2 / \nu\omega_p \qquad R_B = (g\nu)^{-1}u_*^3\beta. \qquad \beta = g/u_*\omega_p$$

Wave Age based on wind stress

CO_2 – Wind speed dependence

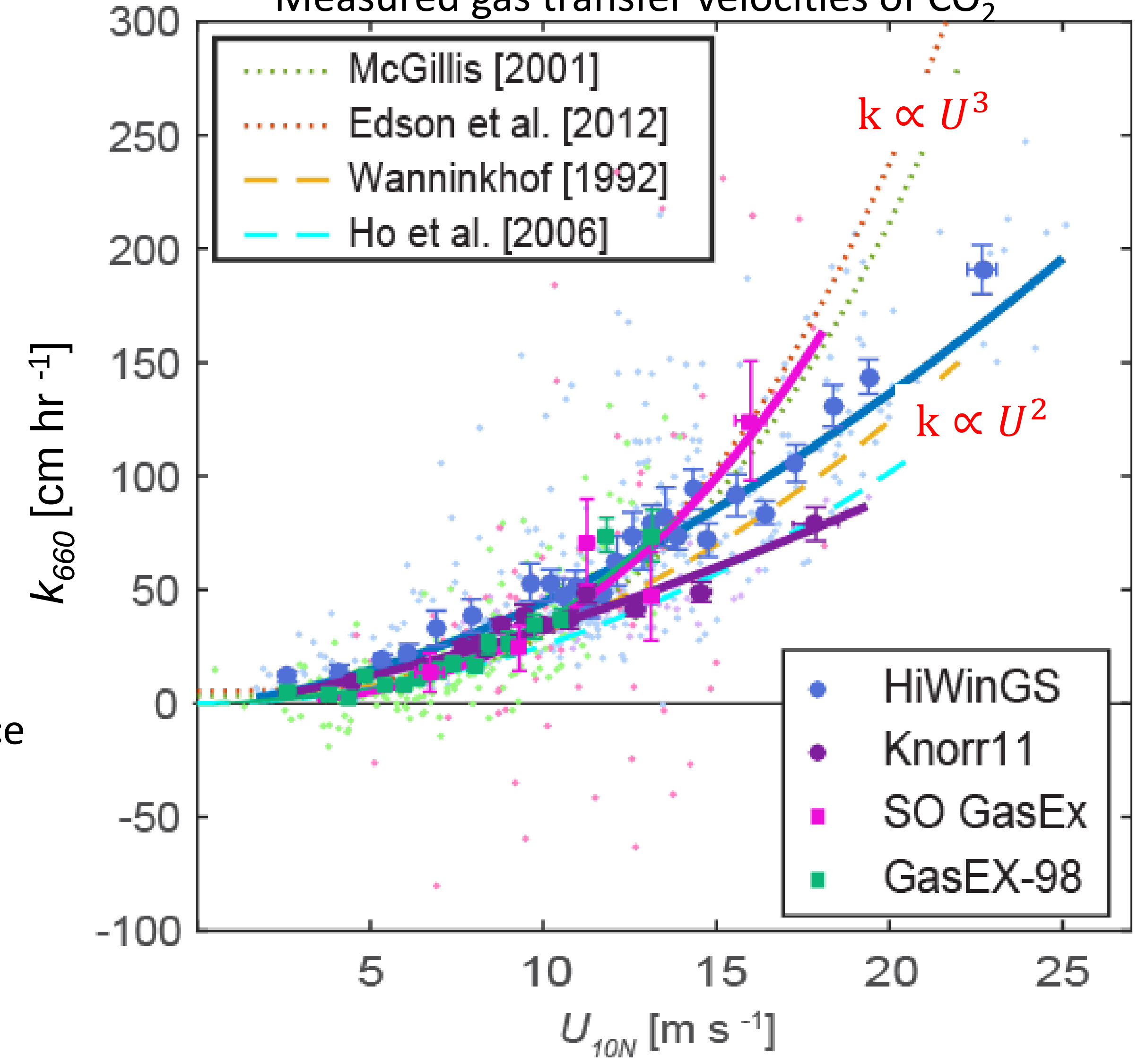
4 distinct
open ocean data sets

Large discrepancies in trends:

GasEx-98 & SO GasEx
close to cubic U_{10N} dependence

HiWinGS & Knorr11
lower than quadratic dependence

Measured gas transfer velocities of CO_2



Brumer et al., (2017). Wave-related Reynolds number parameterizations of CO_2 and DMS transfer velocities. GRL.

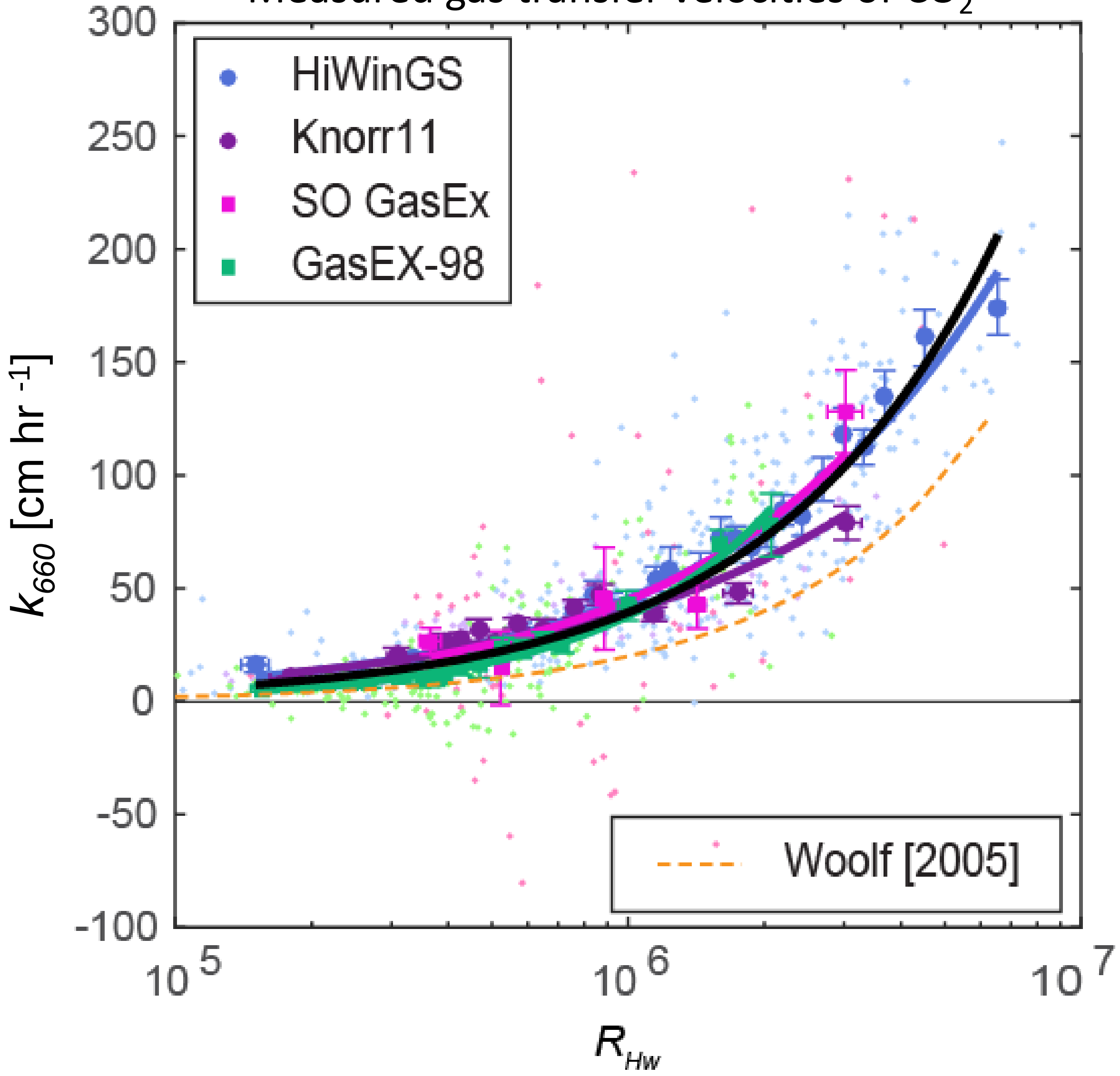
CO_2 – Wave related Reynolds numbers

Reynolds # collapses all 4 data sets!

$$R_{H_w} = \frac{u_* H_s}{\nu_w}$$

Wave-wind Reynolds #

Measured gas transfer velocities of CO_2

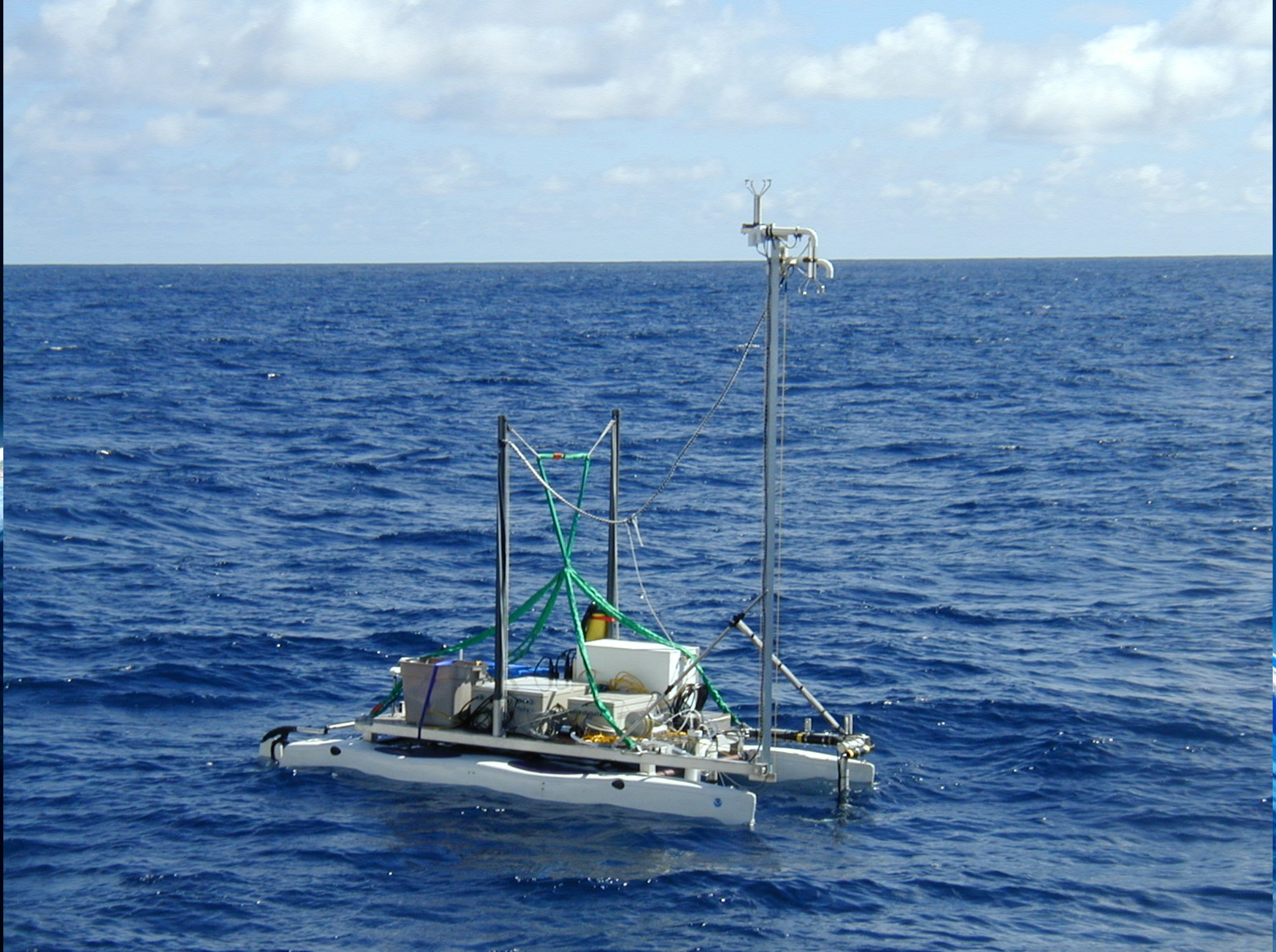


Brumer et al., (2017). Wave-related Reynolds number parameterizations of CO_2 and DMS transfer velocities. GRL.

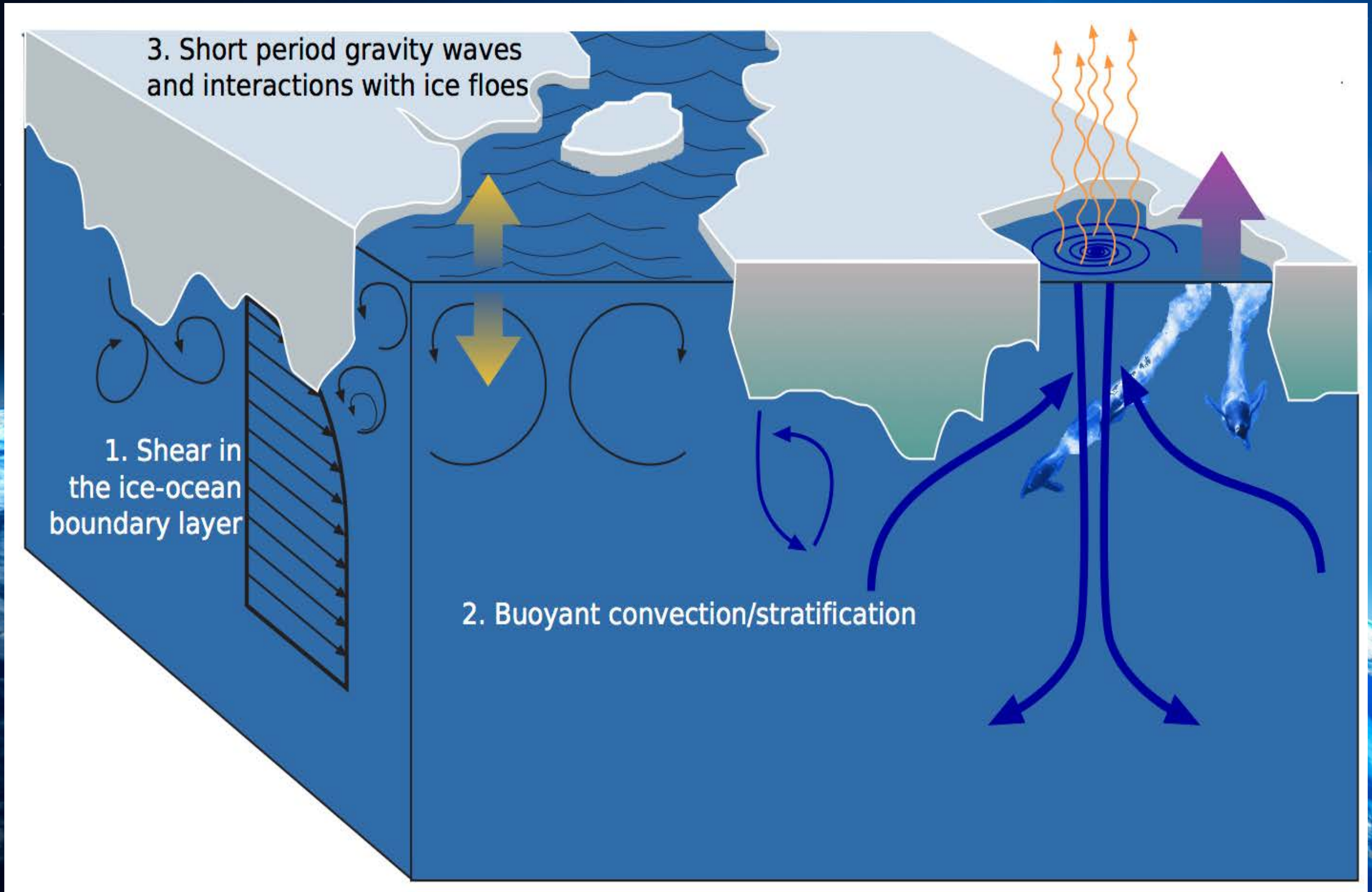

NOAA
R 104


NOAA

LADAS Catamaran



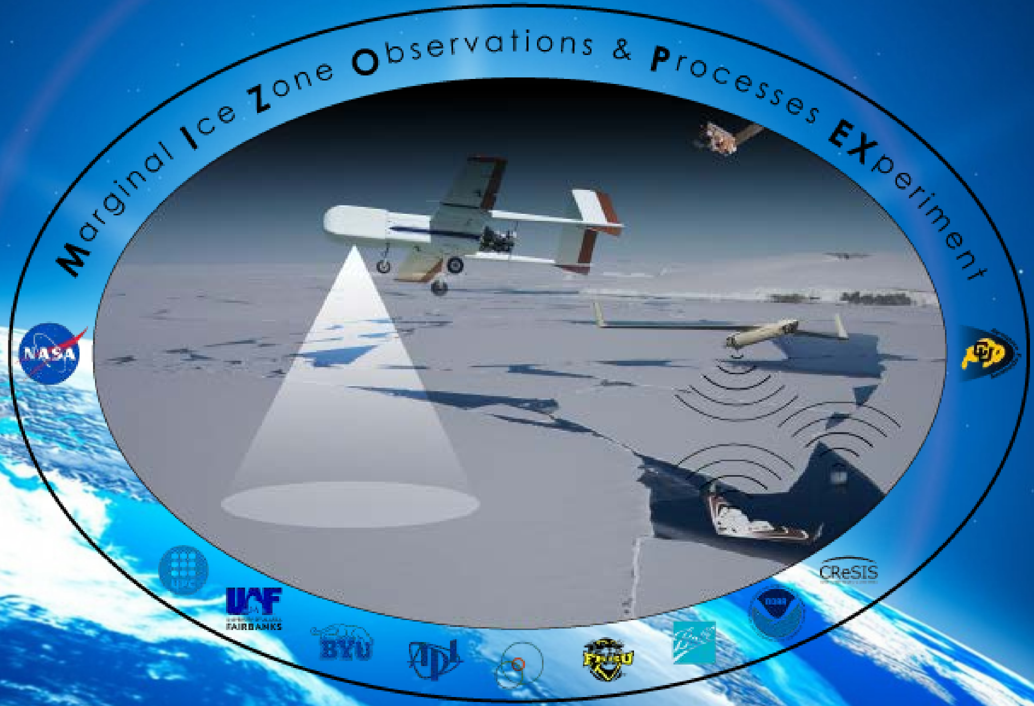
Turbulence Mechanisms in Polar Systems



- Three mechanisms for mixing / turbulence that are not prevalent in low-latitude environments.
- Compare the structure of circulation and mixing of the influx of cold skin SST

UAS Activities at Lamont-Doherty Earth Observatory of Columbia University

NASA



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Science & Technology

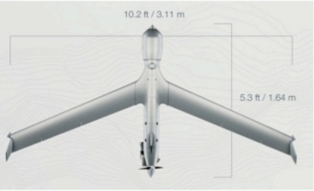
GORDON AND BETTY MOORE FOUNDATION

MIZOPEX 2013

Goals:
- **Assess ocean and sea ice variability in the Alaskan Arctic Ocean (Beaufort Sea/Prudhoe Bay area).**
- **Demonstrate potential for research using multiple unmanned aircraft systems (UAS) in polar regions.**
- **Determine best practices for safe, reliable operations in the National Air Space.**

Overview of the UAF-Operated InSitu ScanEagle UAS

- Wingspan: 10.2 ft, Length: 4.5 ft
- Weight: 29 lbs (empty), 44 lbs (max takeoff wt.)
- Gas engine (1.9 hp), rear propeller, onboard generator for electric power
- 48 knot airspeed (cruise)
- Catapult launch, wing tip capture via cable
- Autonomous flight control with GCS control while in line of sight radio range (approx 40 km)
- Iridium satcom for over the horizon operations
- Endurance: 20+ hours
- Ceiling: 19,500 ft.
- Payload: up to ~6 lbs.
- Has received numerous FAA Certificates of Authorization, thousands of flight hours achieved.

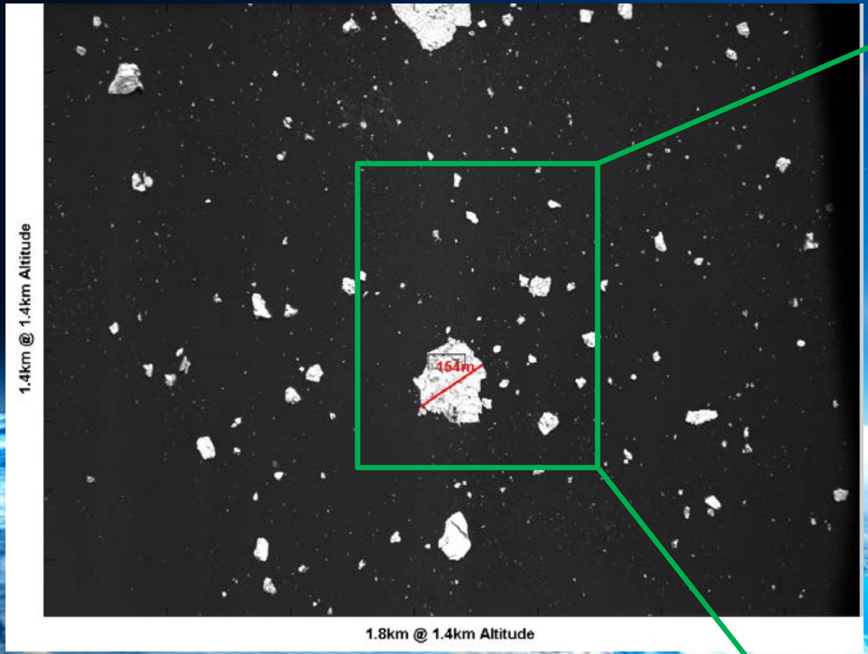


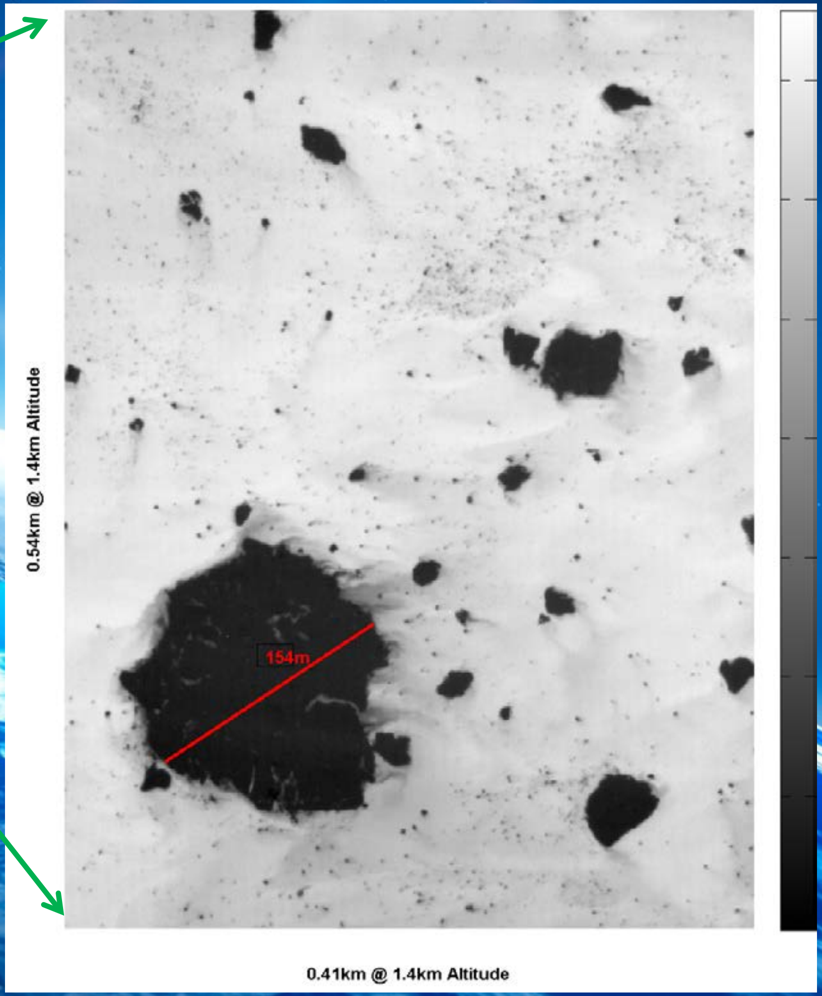
MIZOPEX 2013

MIZOPEX 2013

MIZOPEX: Turbulence Mechanisms in Polar Systems

Measurements of Visible and Infrared Imagery from LDEO Payload on Scan Eagle



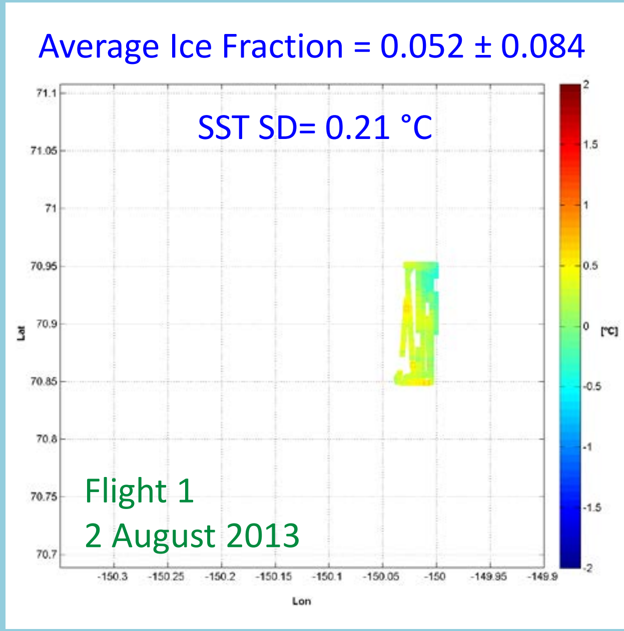


- Mechanisms for mixing / turbulence that are prevalent in polar environments.
  - Shear at the ice-ocean boundary layer
  - Interaction of ice floes with surface currents and waves
- Infrared imagery show cold wakes mixing near-surface ocean in the lee of ice floes.

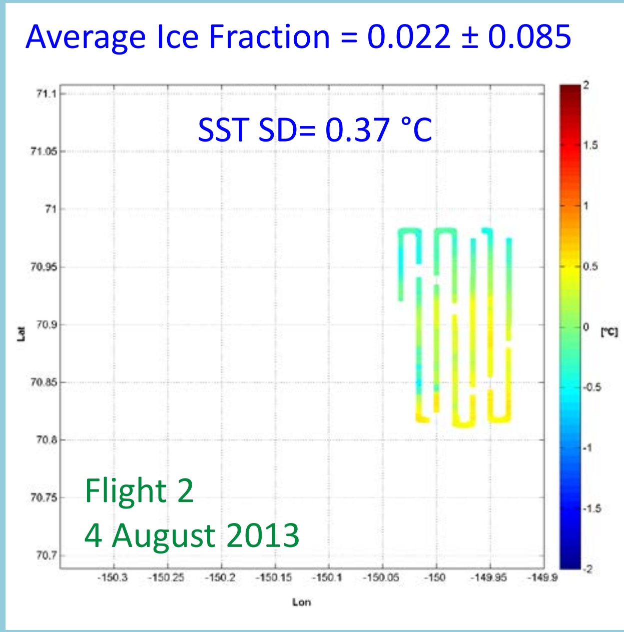
Visible (Left): 1.4 km x 1.8 km
Infrared (Right): 0.54 km x 0.41km

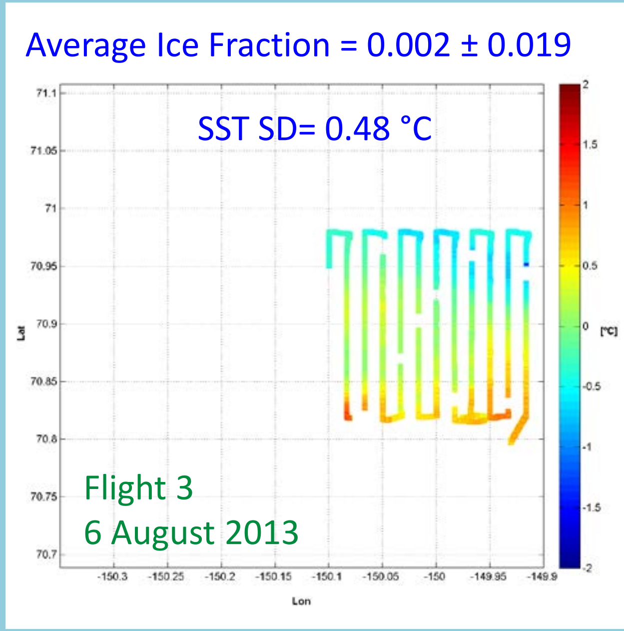
Christopher J. Zappa, Lamont-Doherty Earth Observatory, Columbia University

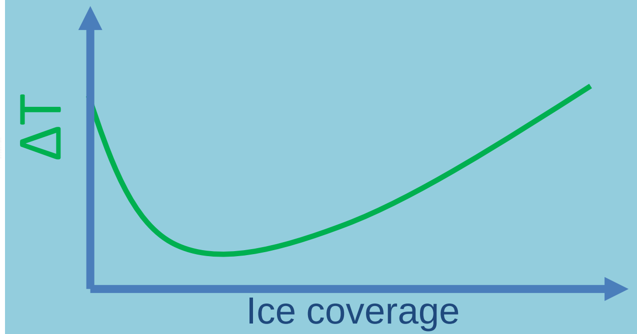
MIZ Transition Over Beaufort Sea



- Data suggests turbulence due to increased floe concentration enhances the mixing of skin SST variability
- We hypothesize that ΔT first decreases with floe concentration up to a certain point where concentration starts inhibiting turbulence and melt processes dominate.
  - Skin SST variability results during MIZOPEX are supported by measurements during experiments at CRREL.

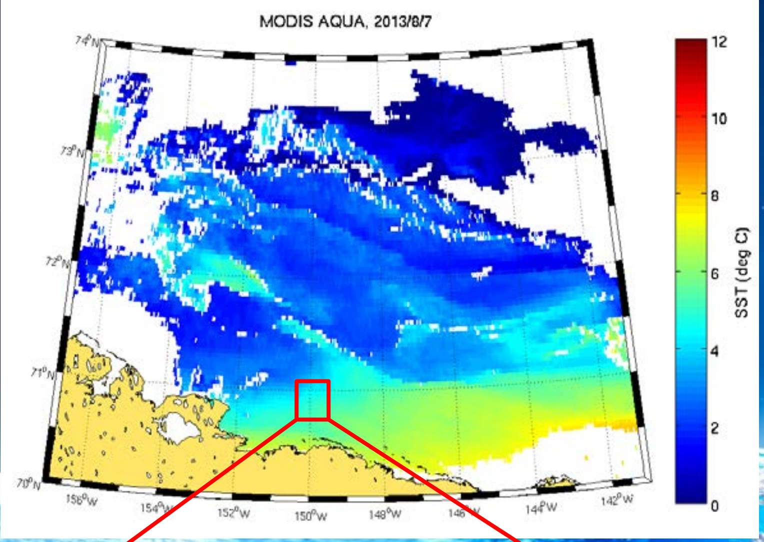


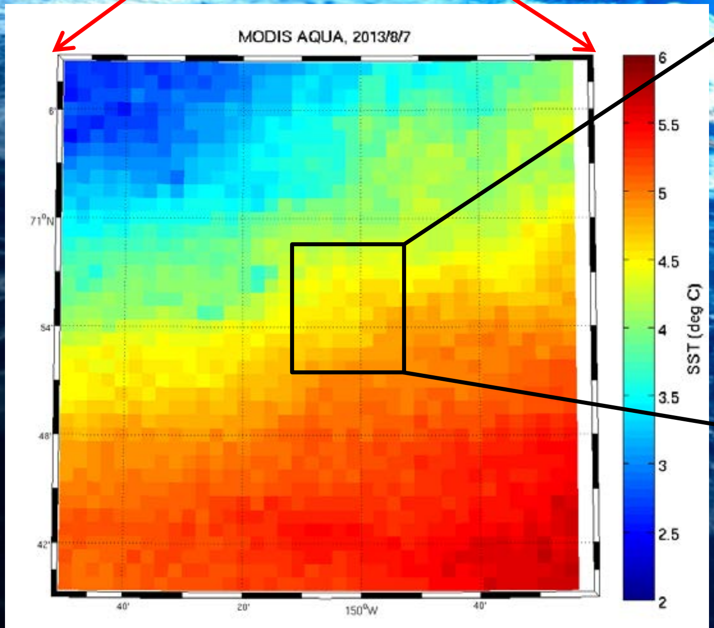




Satellite View of MIZOPEX Transition

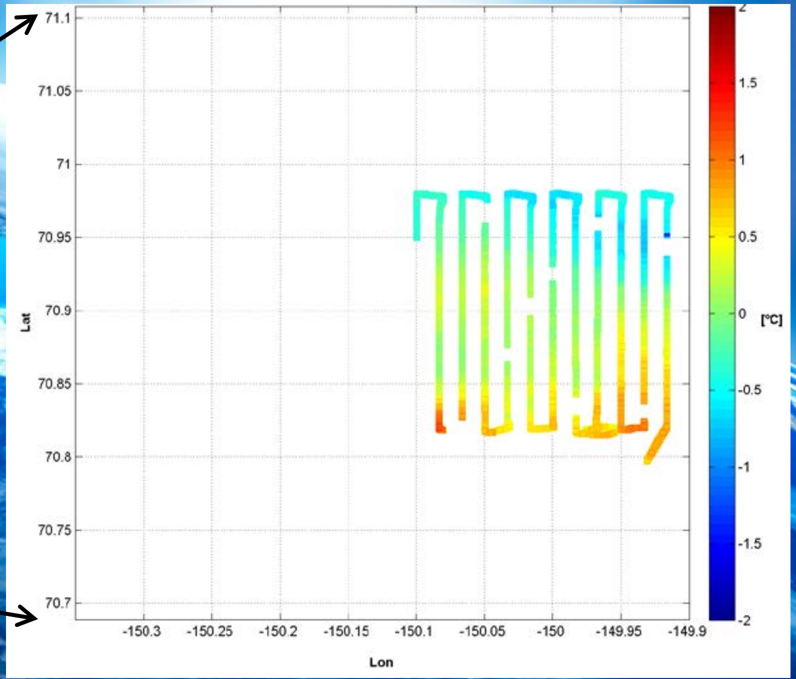
Measurements of Infrared Imagery from LDEO Payload on Scan Eagle





- Objective here to see if variability in the satellite SST fields is consistent with that observed in the airborne data as ice melts away (or if the satellite data is just too coarse to say anything).

- Image shows the similar N-S gradient observed in UAV data (roughly 1.5 °C).



MODIS Aqua image for 7-August 2013 (Top) and a Zoom in view (Bottom). The image is roughly a 50x50 km square. Unfortunately, we get just this one good satellite look due to cloud cover issues.

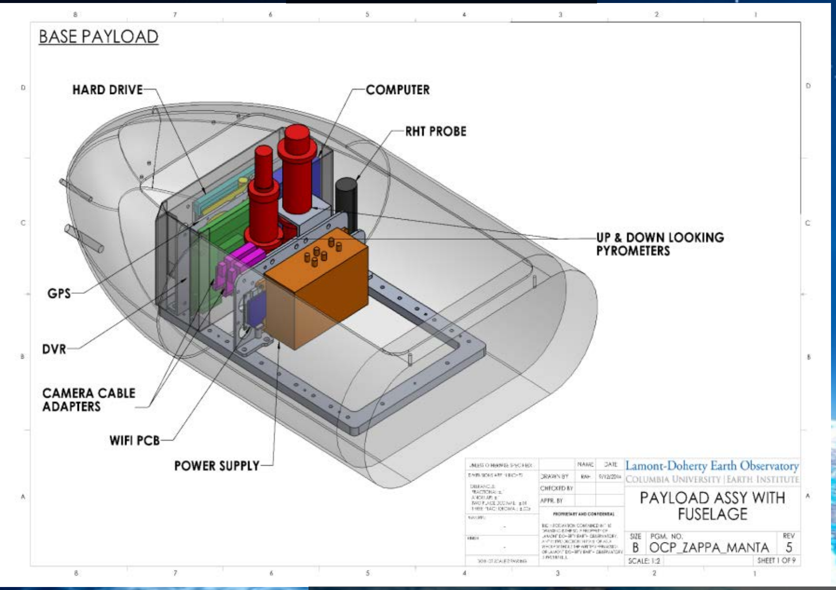
Christopher J. Zappa, Lamont-Doherty Earth Observatory, Columbia University

Moore Foundation: UAS Payload Development

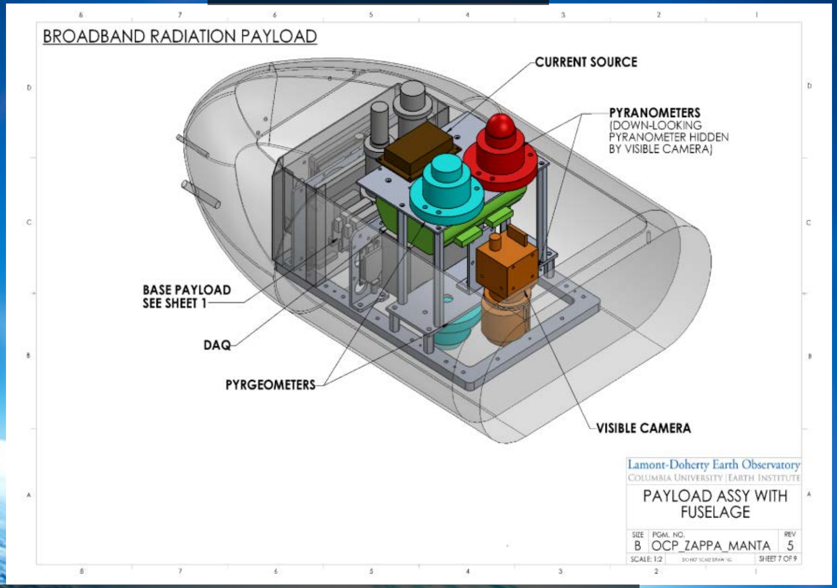
GORDON AND BETTY MOORE FOUNDATION

UAS Payload Development

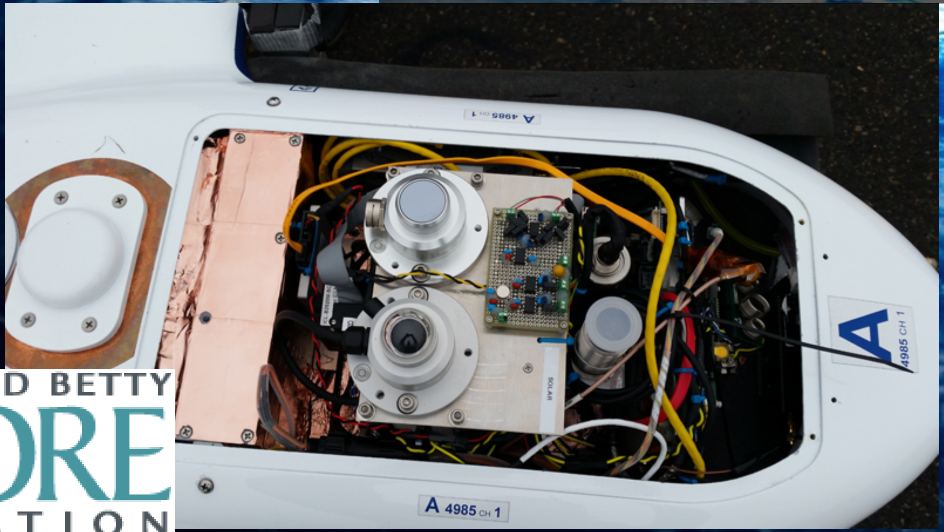
BASE Payload



Sensor Module



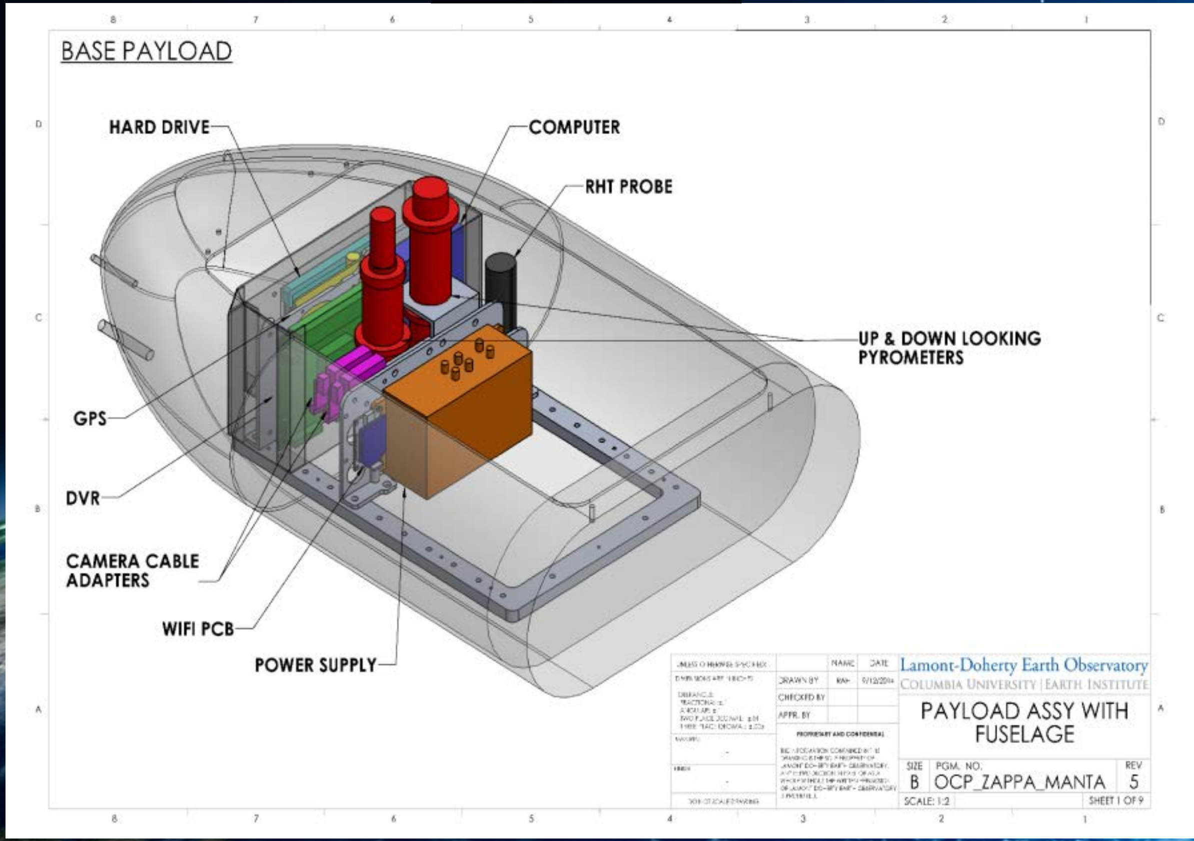
BASE payload allows for quick change between sensor payloads



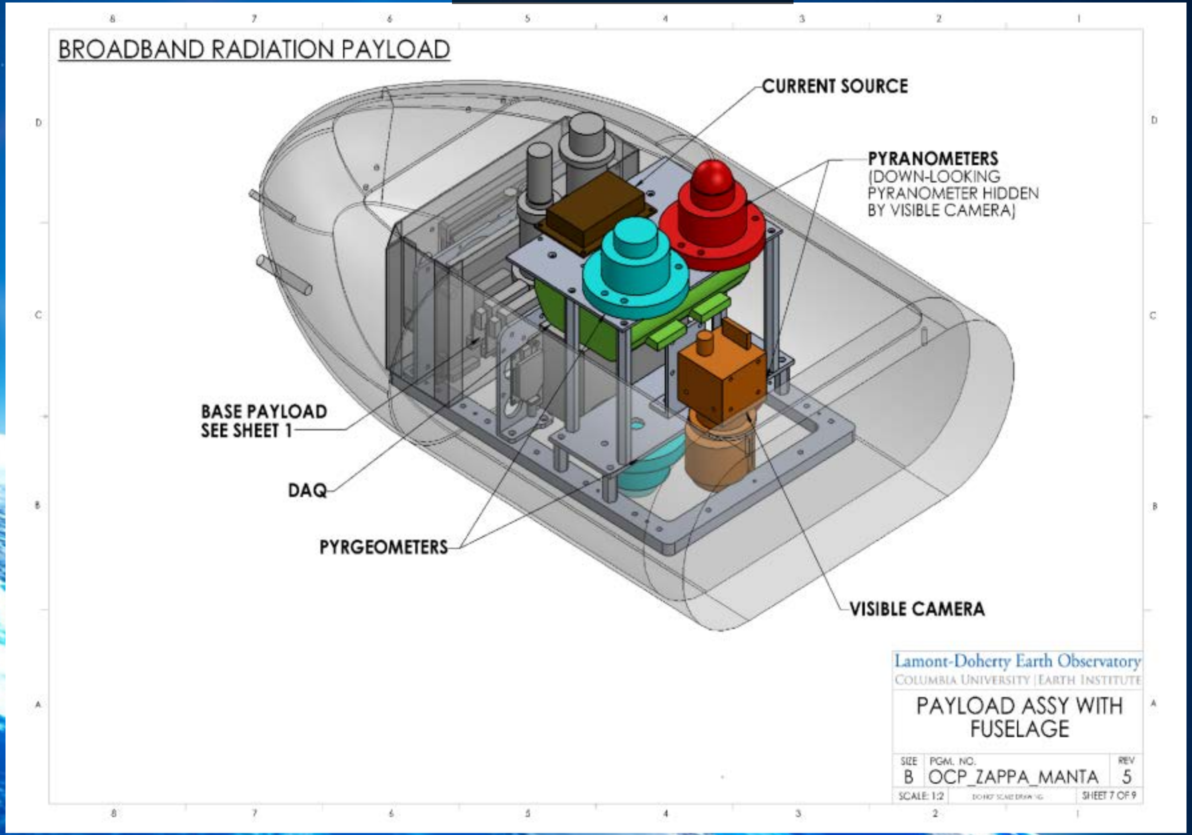
GORDON AND BETTY MOORE FOUNDATION

UAS Payload Development

BASE Payload



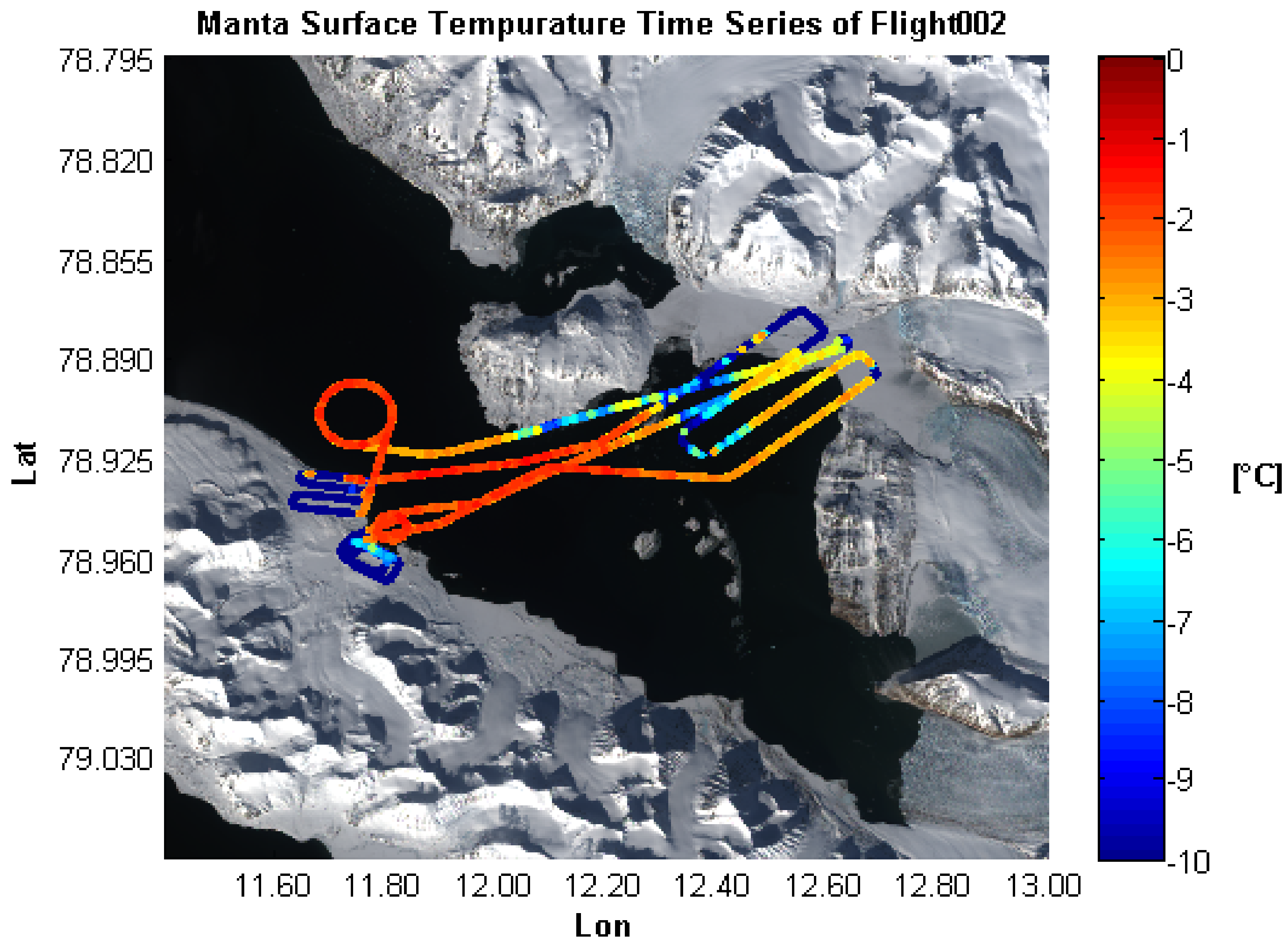
Sensor Module



BASE payload allows for quick change between sensor payloads

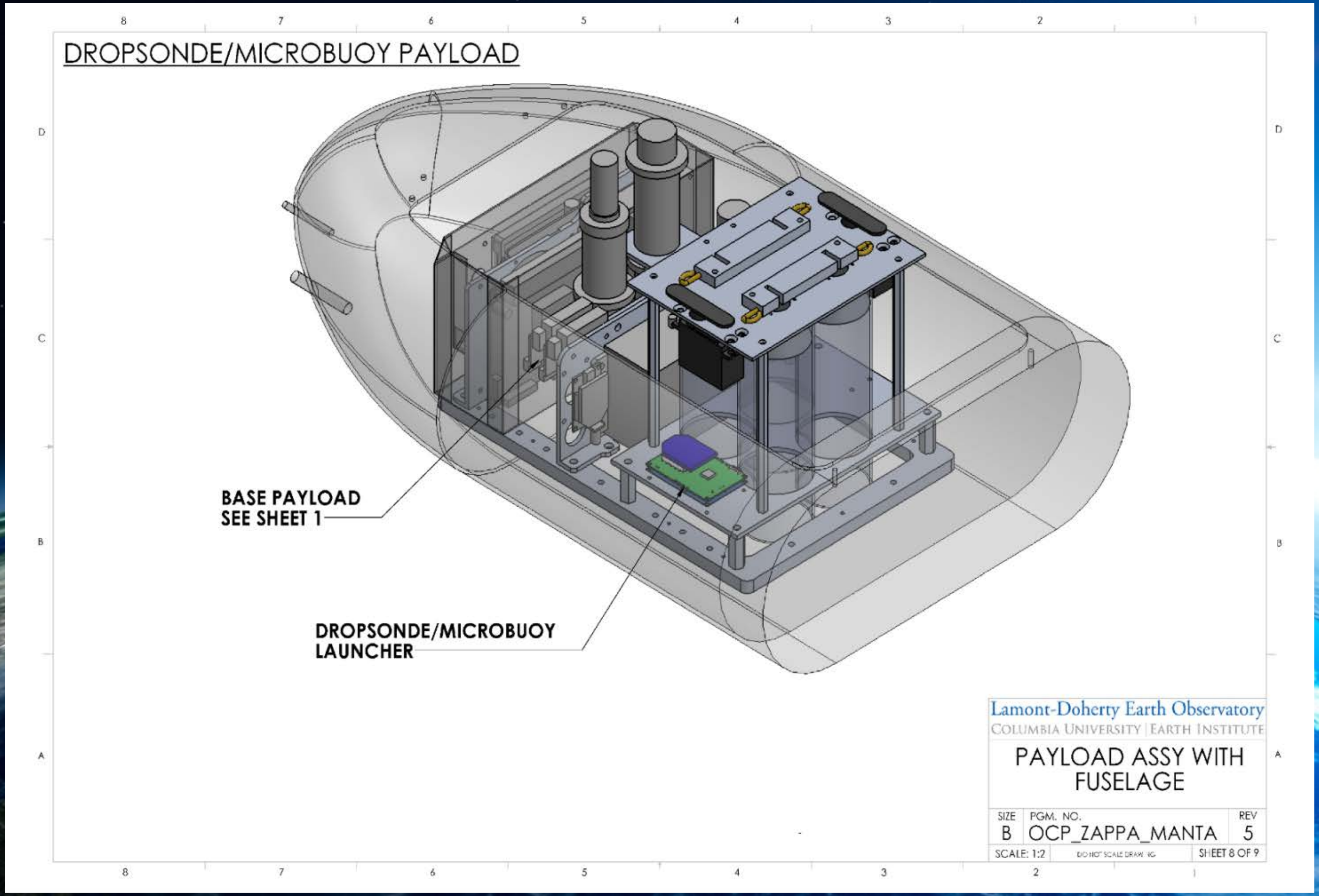
GORDON AND BETTY MOORE FOUNDATION

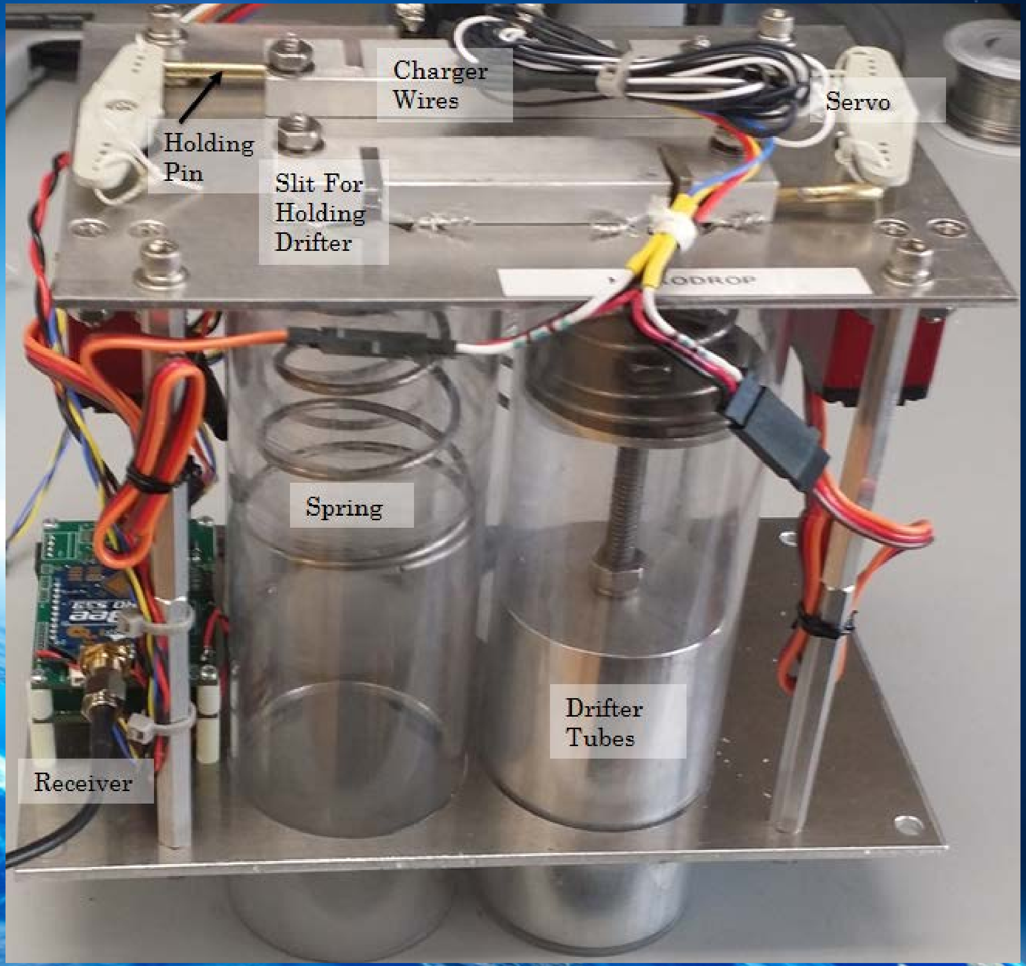
Sea/Ice Surface Skin Temperature



GORDON AND BETTY MOORE FOUNDATION

Dropsonde / Microbuoy (DDmD) Payload



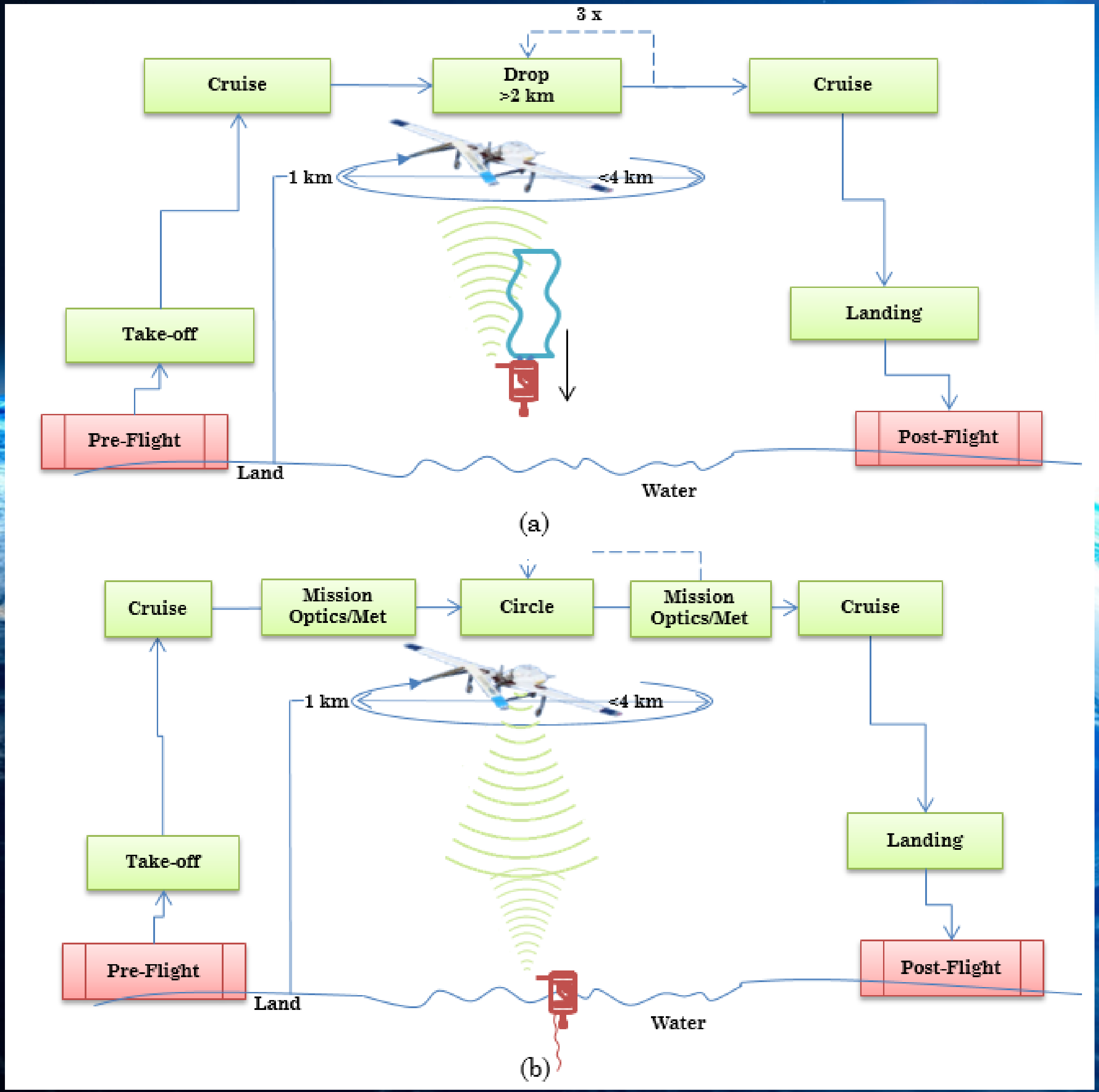


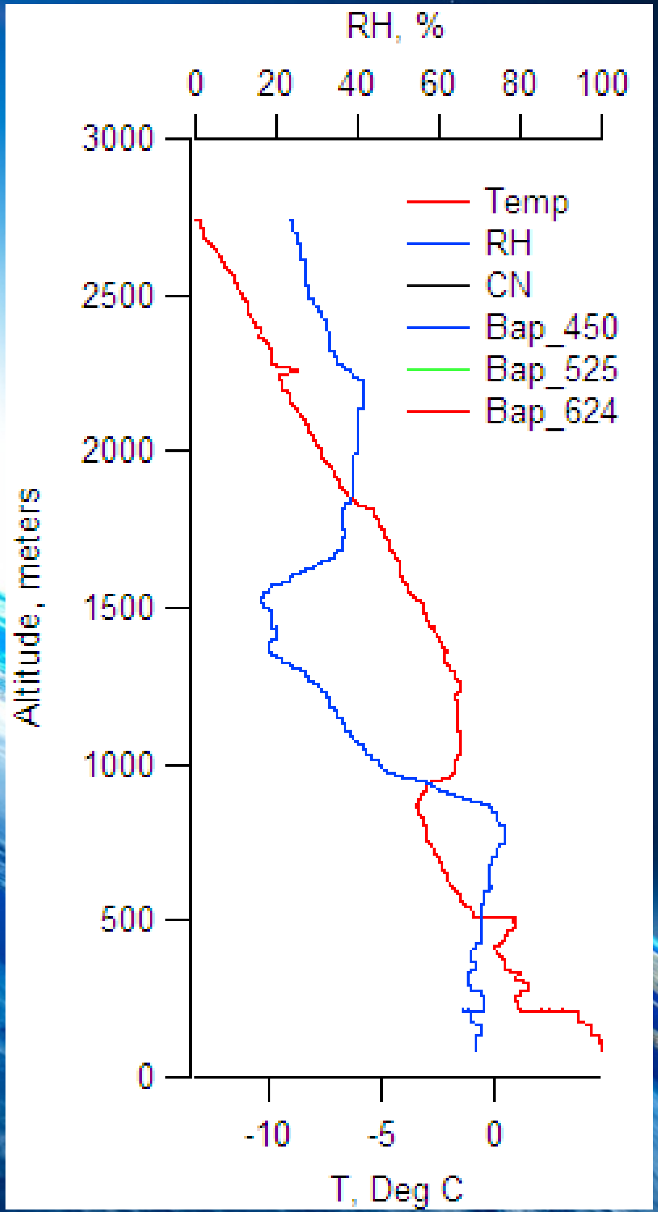
GORDON AND BETTY MOORE FOUNDATION

Dropsonde - Atmospheric Temperature, RH, and Pressure profiles

Microbuoy - upper ocean (1-m) temperature and salinity with telemetry

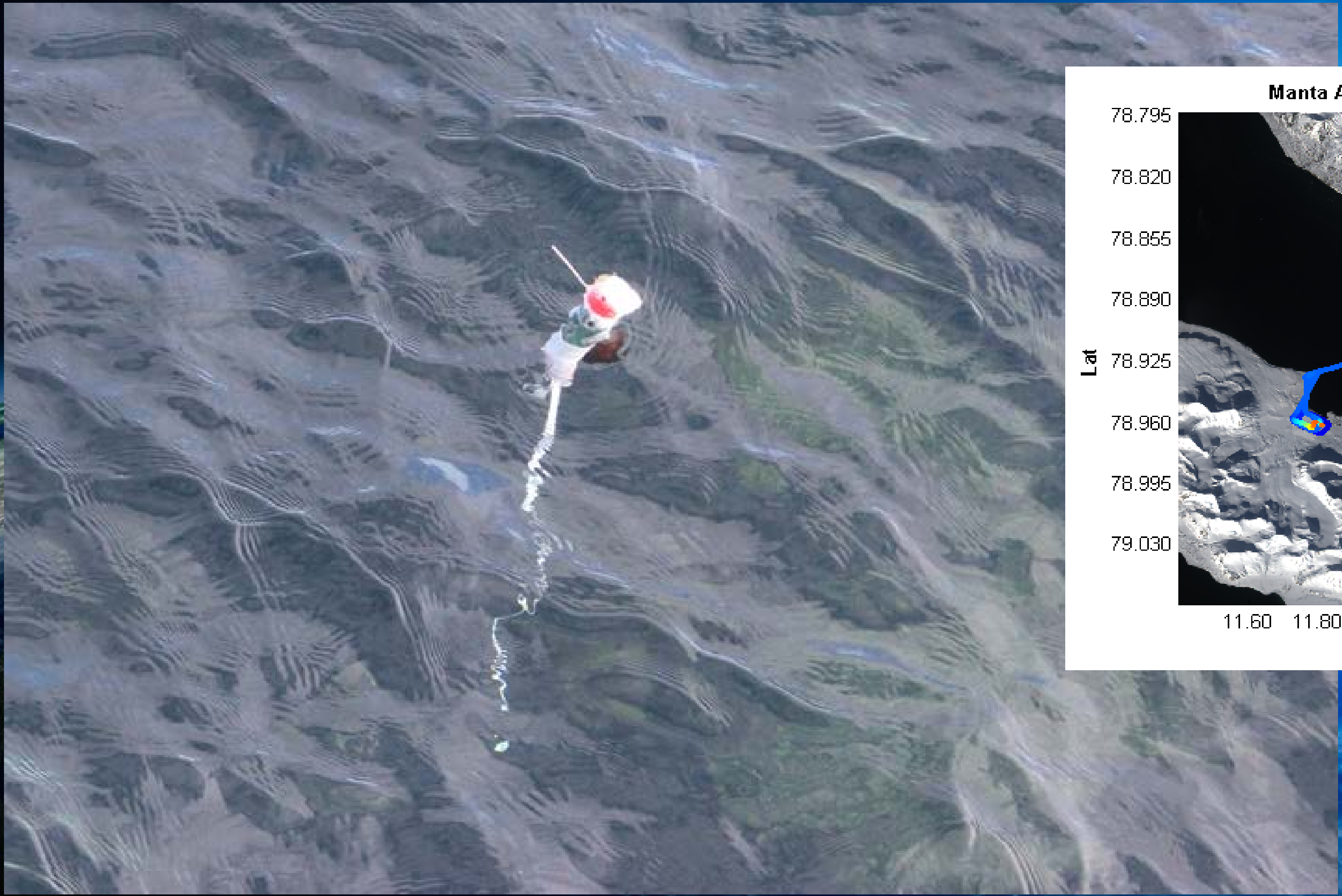
Dropsonde / Microbuoy (DDmD) Payload

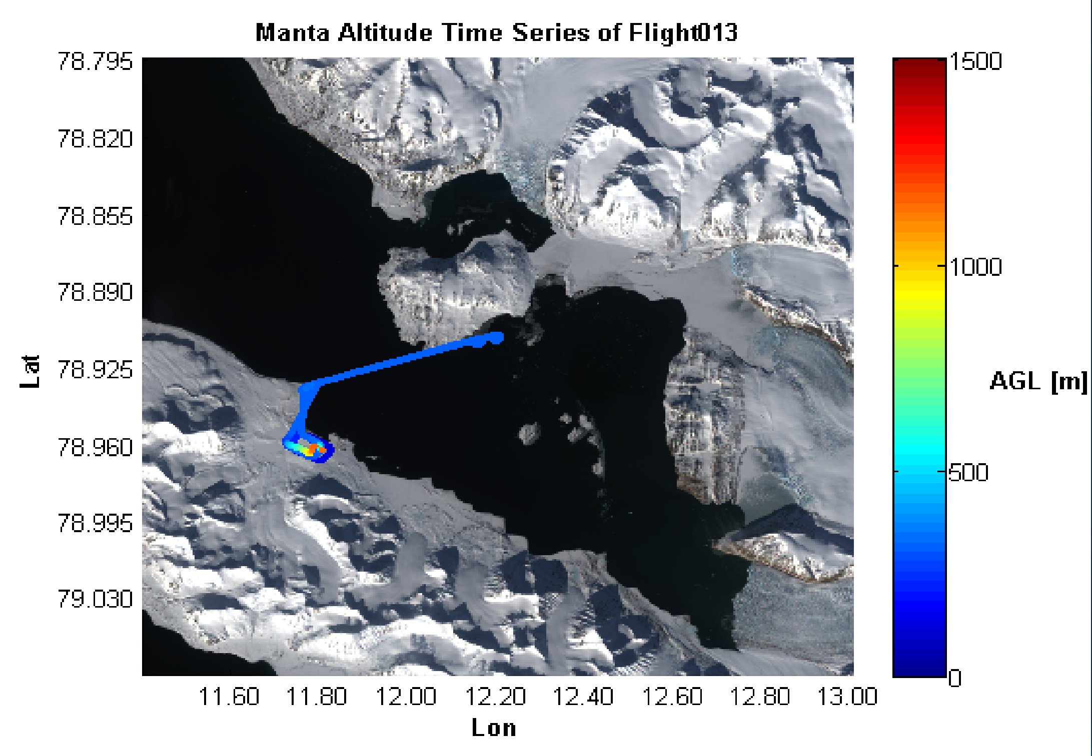




GORDON AND BETTY MOORE FOUNDATION

Dropsonde / Microbuoy (DDmD) Payload

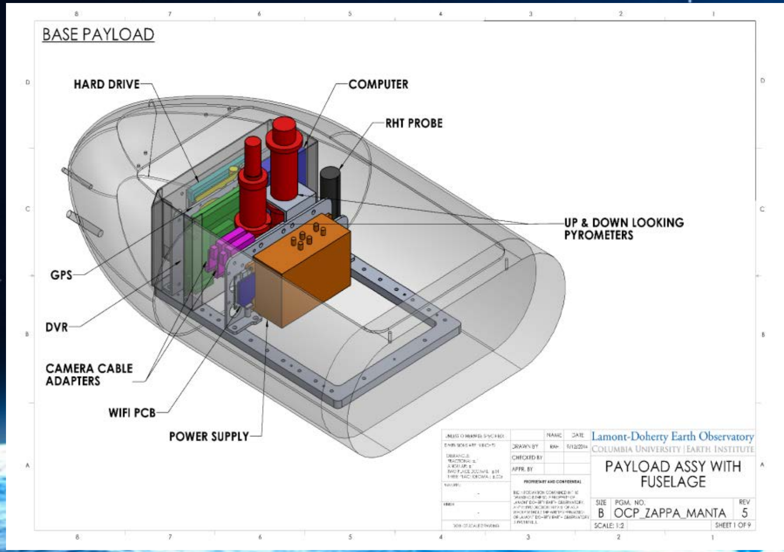




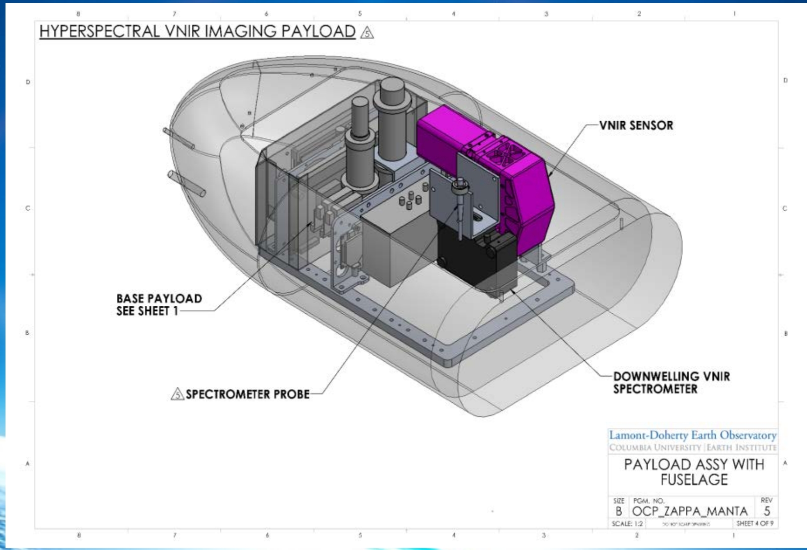
GORDON AND BETTY MOORE FOUNDATION

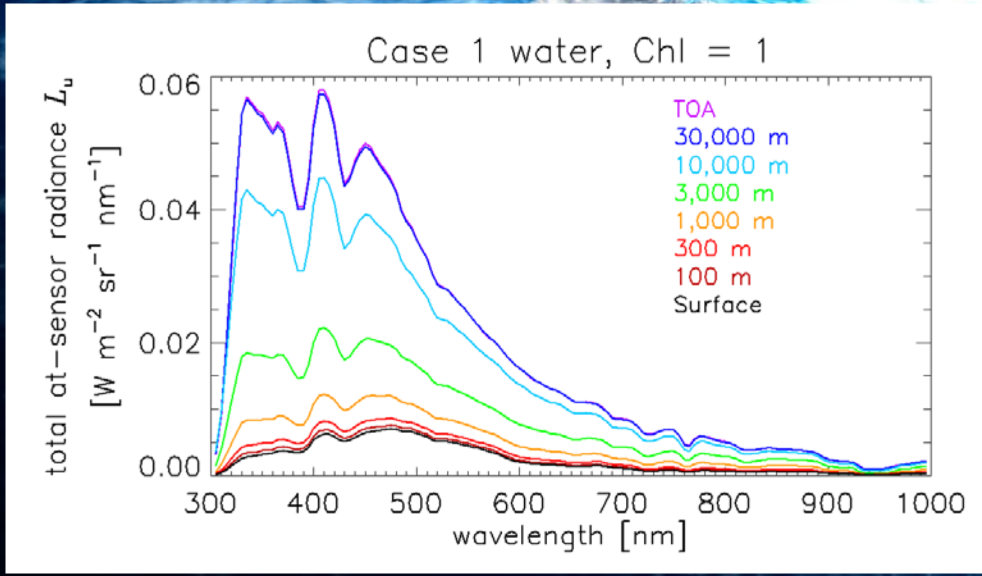
Hyperspectral Payload Development

BASE Payload

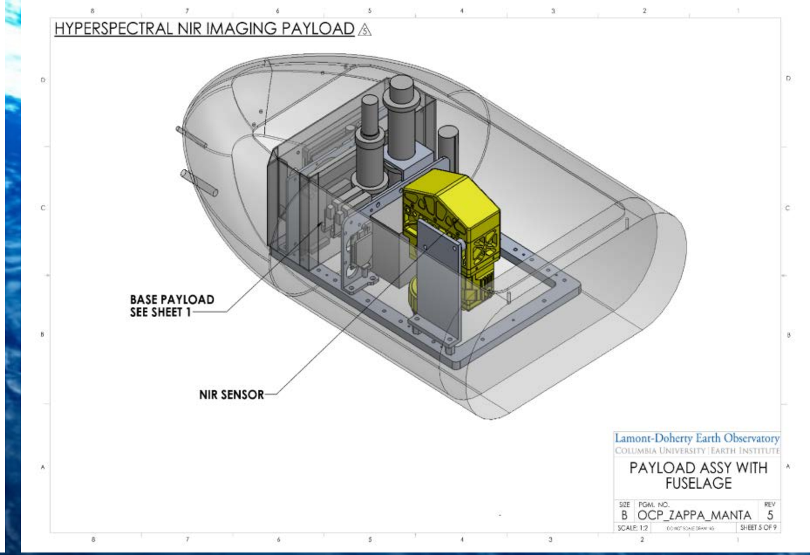


VNIR Module





NIR Module



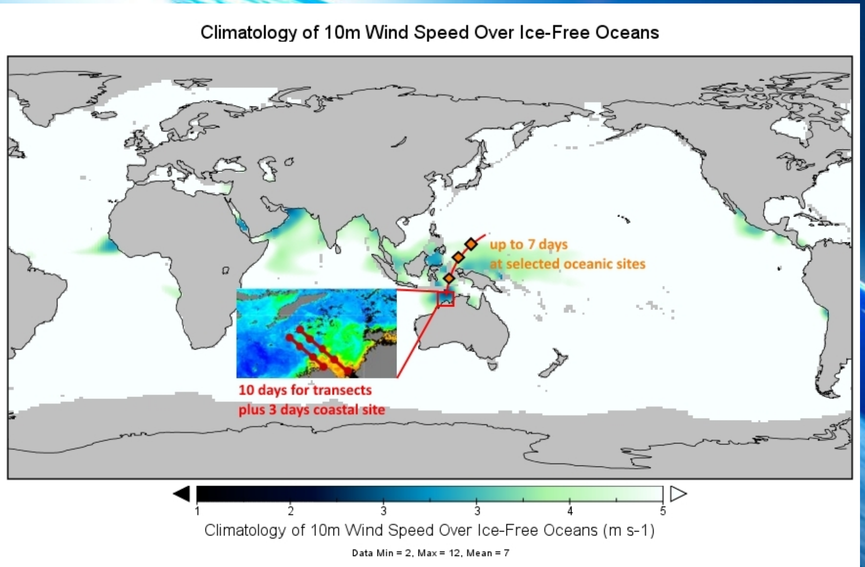
UAS Payloads

Table 1: Implemented science payloads and applications	
Payload	Sensing technologies
VIS-TIR*	High-resolution broadband visible (400-700 nm) imager, uncooled microbolometer (8-14 μm) imager sensitive to 0.05°C for skin sea surface temperature (SST) mapping, whitecapping, and other upper ocean processes.
Hi-TIR*	Cooled infrared (7.7 – 9.5 μm) imager sensitive to 0.02°C for skin SST mapping, whitecapping, and other upper ocean processes.
HYP-VNIR*	Hyperspectral visible (300-1000 nm) imaging spectrometer with better than 3 nm spectral resolution for spectral radiance measurements of the upper-ocean to determine ocean color and biogeochemical mapping. Upward-looking narrow FOV spectrometer provides measurements for estimates of spectral albedo of varying surfaces including ocean.
HYP-NIR*	Hyperspectral near-infrared (900-1700 nm) imaging spectrometer with better than 3 nm spectral resolution for spectral radiance measurements of the near-surface ocean to determine ocean color and biogeochemical mapping.
Li-MET	LiDAR for wave height and surface roughness; fast response 3D wind speed and direction (100 Hz), fast response temperature (50 Hz), fast response relative humidity (100 Hz) for estimating momentum, latent heat and sensible heat turbulent fluxes.
RAD*	Upward- and downward-looking pryanometer (broadband solar 285-3000 nm) and pyrgeometer (broadband longwave; 4.5-40 μm) to measure full hemispheric irradiance to understand the surface energy budget and map albedo of varying surfaces including the ocean. High-resolution broadband visible (400-700 nm) imaging is used to map whitecapping and other upper ocean processes.
DDμD*	Drone-Deployed Micro-Drifters with launcher for in-flight ejection of up to four micro-dropsonde packages. The DDμD measures temperature, pressure, and relative humidity as it descends through the atmosphere. Once it lands on the ocean's surface, it deploys a string of sensors that measures temperature and salinity of the upper 2-3 meters of the ocean at fifteen minute intervals for up to two weeks as a buoy. The ocean sensors on the DDμD collect and store data and then transmit the data back to the UAS on subsequent flights from up to 10 miles away.
***also included upward- and downward-looking pyrometers (8-14 μm) to measure narrow field-of-view (FOV) skin SST and ice-surface temperature.**	

Current Directions – R/V Falkor

Current Directions – R/V Falkor

- Cruise from R/V Falkor in the Northwest Australian Continental Shelf
- Payloads developed for Manta UAS will be integrated onto Latitude Engineering HQ-60.
- Airborne surveys of the Sea Surface Microlayer from Latitude UAVs as well as in situ measurements of the SSM chemistry and biology from catamaran, drifters, and buoys.
- Measurements: ocean surface gravity-capillary wave spectra (*O*(1-0.001)m) using LIDAR and polarimetric imaging; complete chemical and biological quantification and characterization of the biogenic slicks from autonomous catamarans; and quantification and characterization of the near-surface ocean temperature, salinity, TKE dissipation rate, and currents from a drifting spar buoy and in the mixed-layer from autonomous sub-surface profiling



Future Directions – UAS from Ships

SCHMIDT OCEAN INSTITUTE

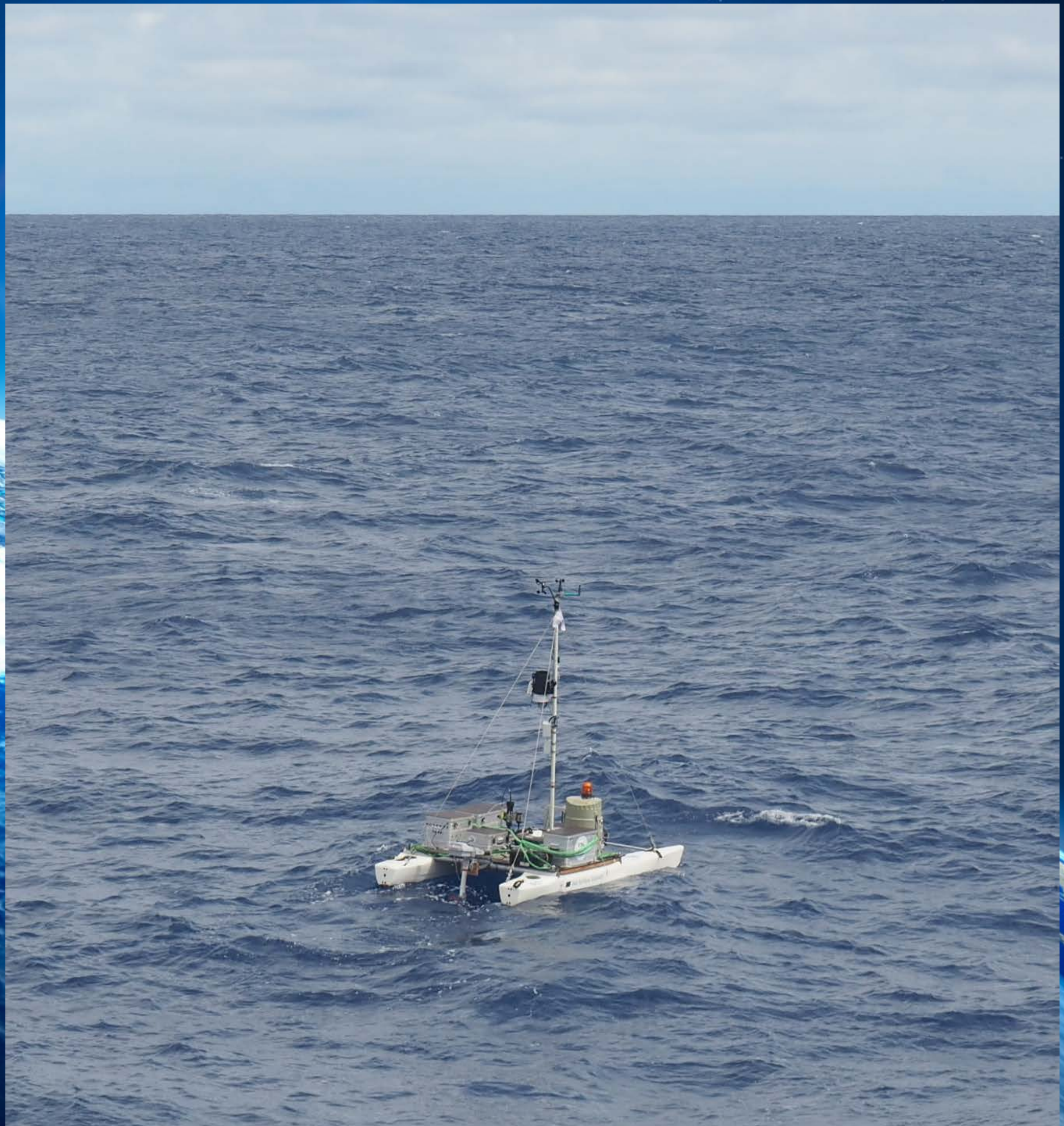
Future Directions – UAS from Ships

SCHMIDT OCEAN INSTITUTE

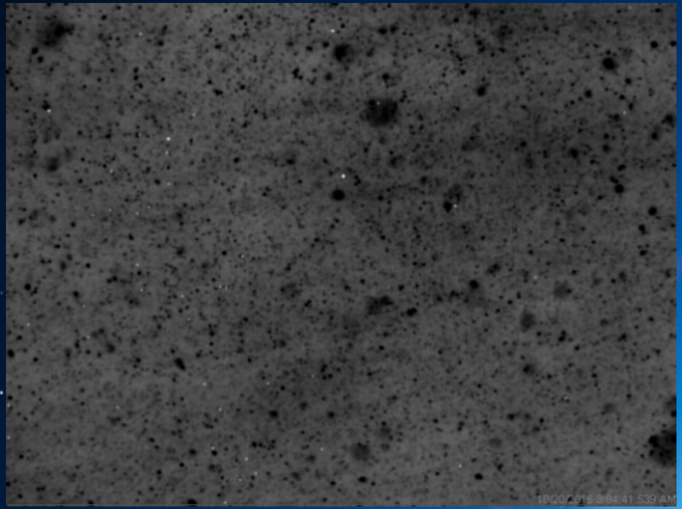
Future Directions – UAS from Ships

SCHMIDT OCEAN INSTITUTE

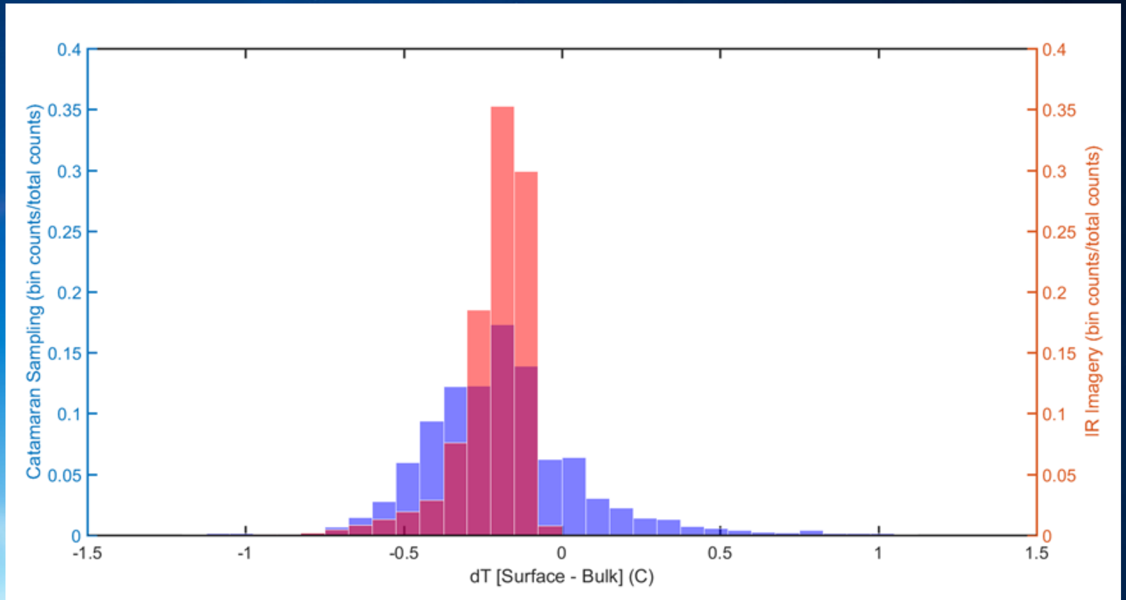
Current Directions – UAS from Ships

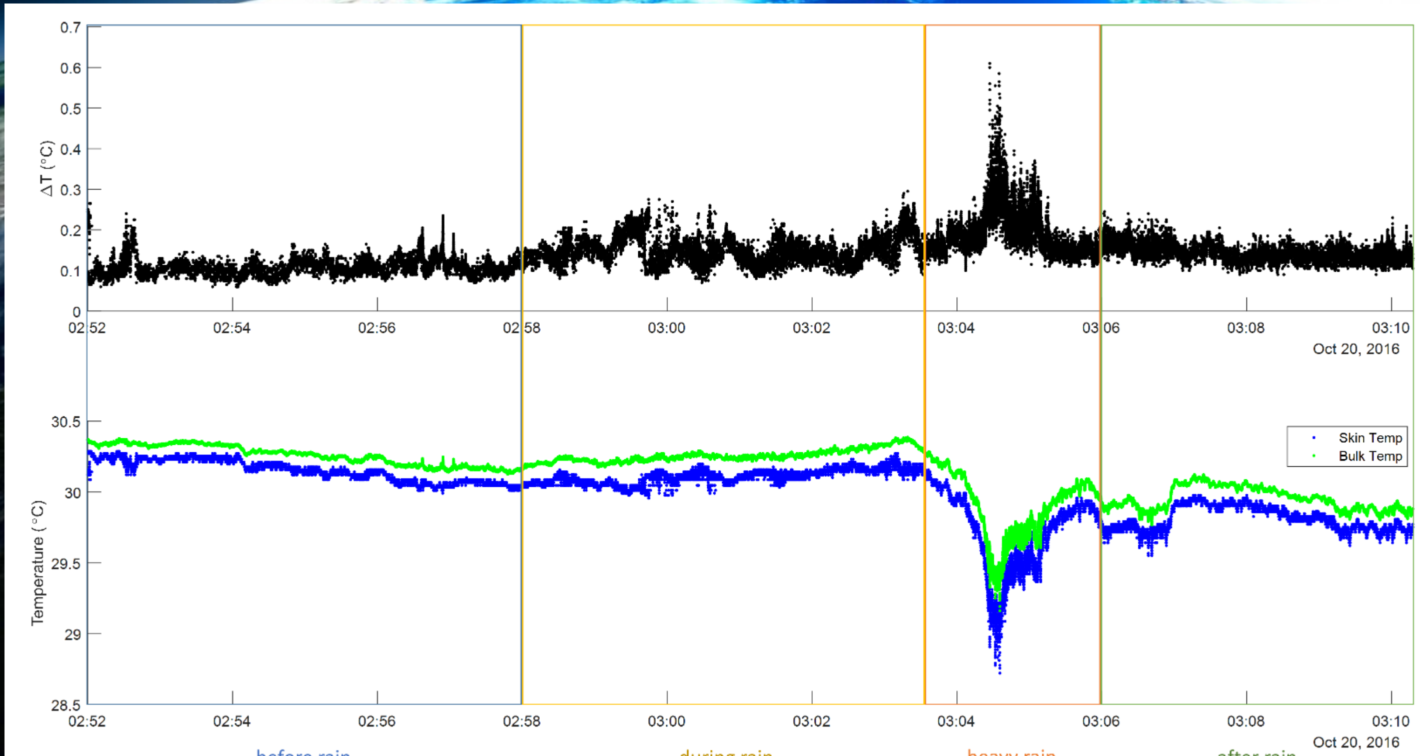


SCHMIDT
OCEAN
INSTITUTE

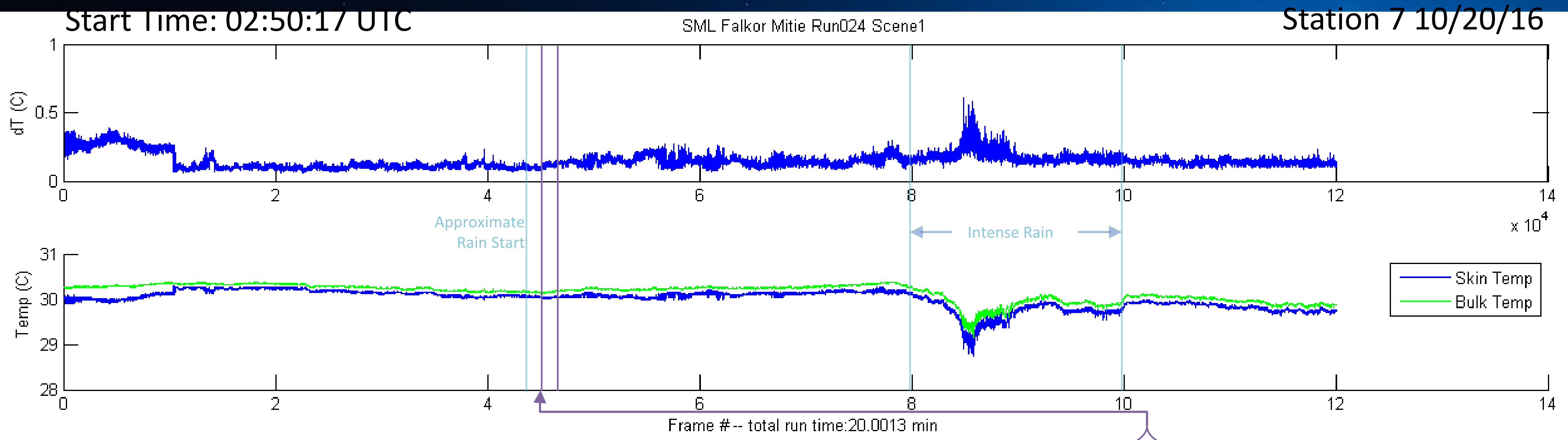


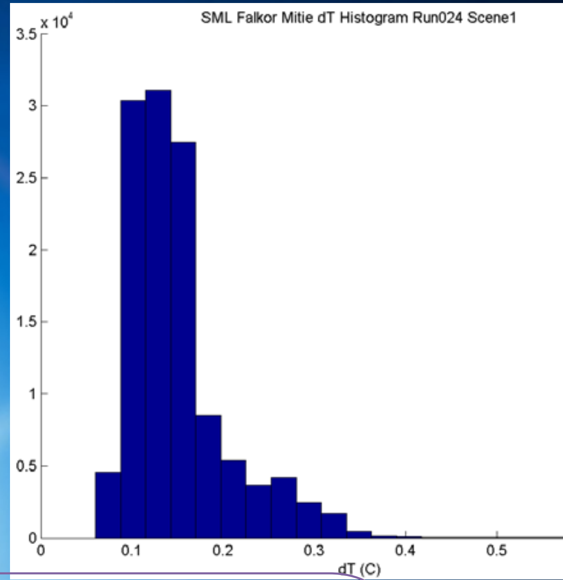
Ocean Cooling Due to Rain





Heavy rain fall event (Sta 7, Timor Sea)

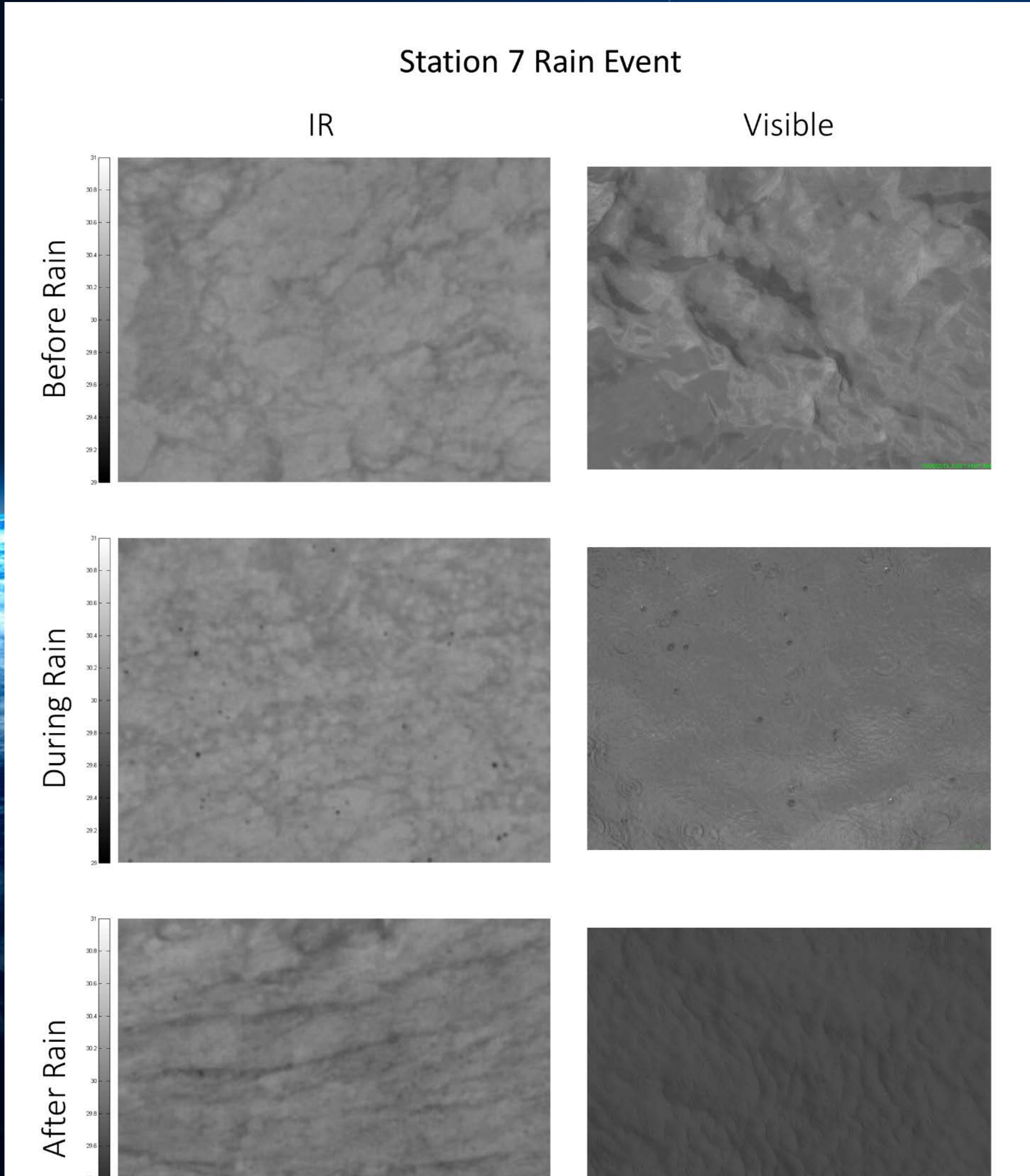




Polarimeter

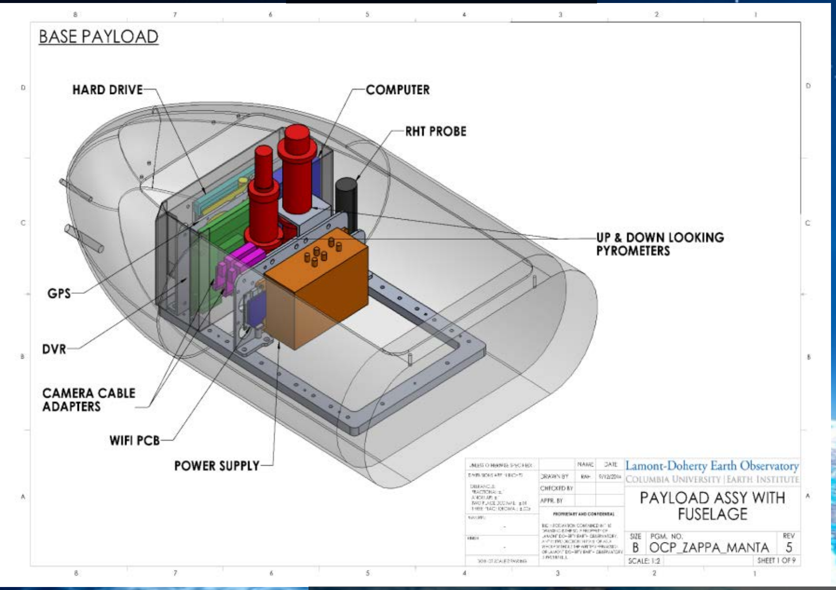
MITIE IR

Heavy Rain Fall Event (Sta 7, Timor Sea)

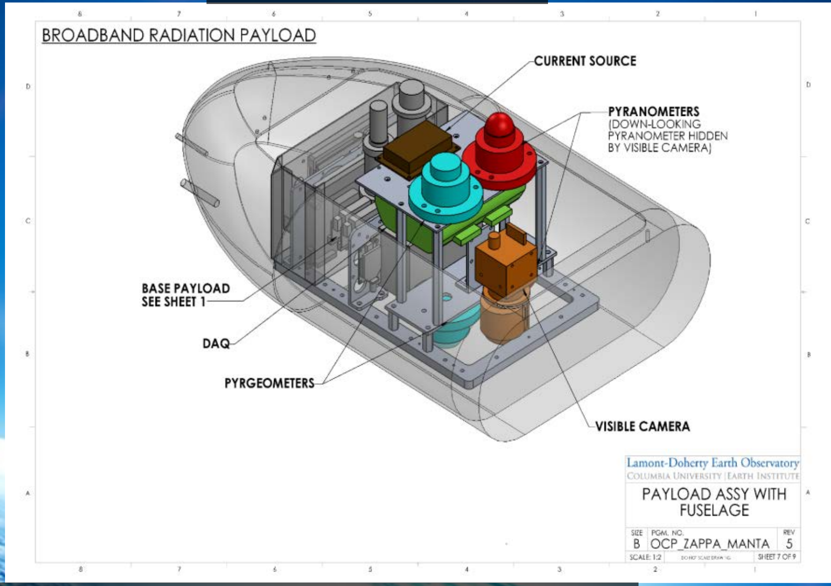


UAS Payload Development

BASE Payload

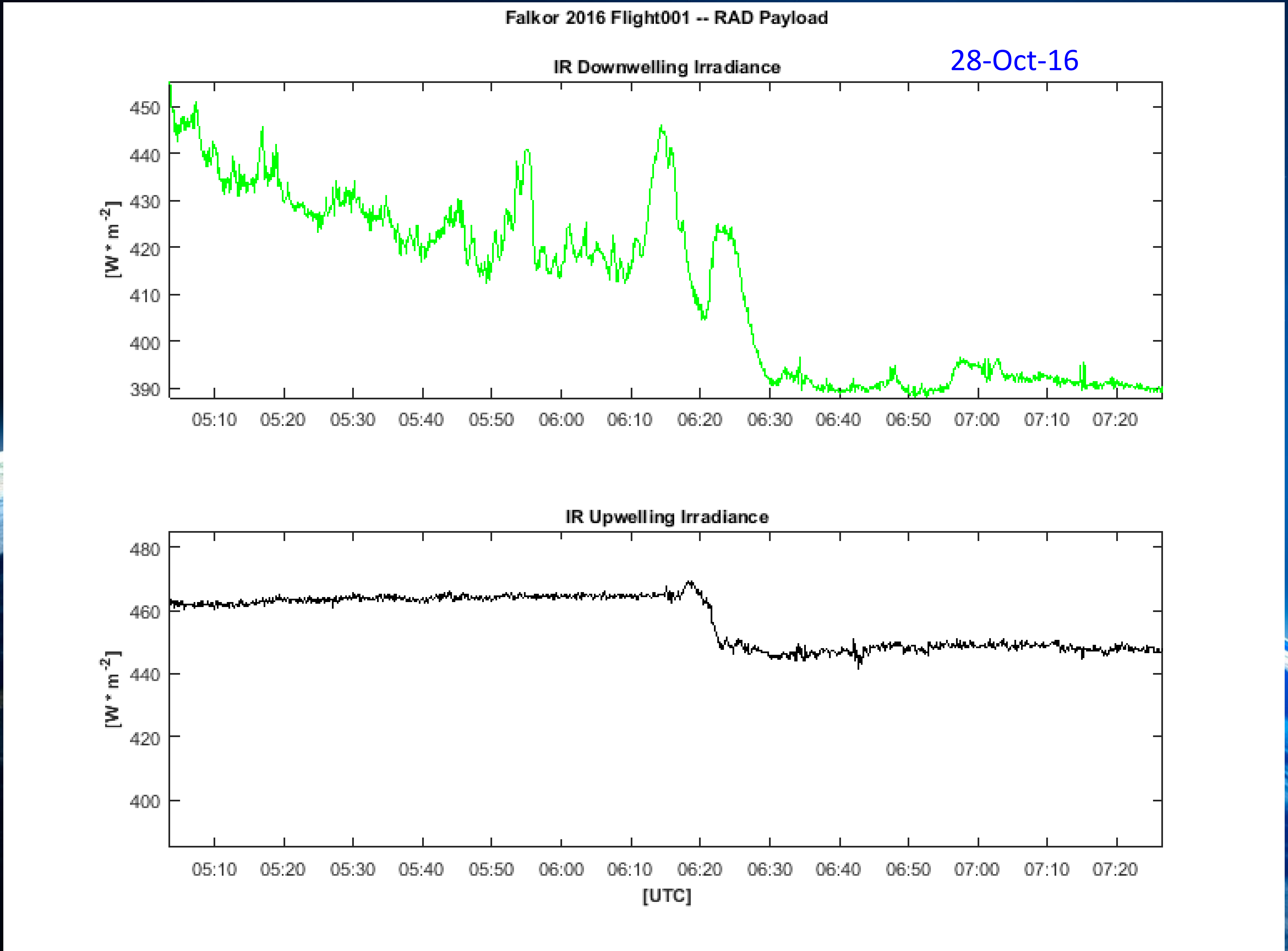


Sensor Module

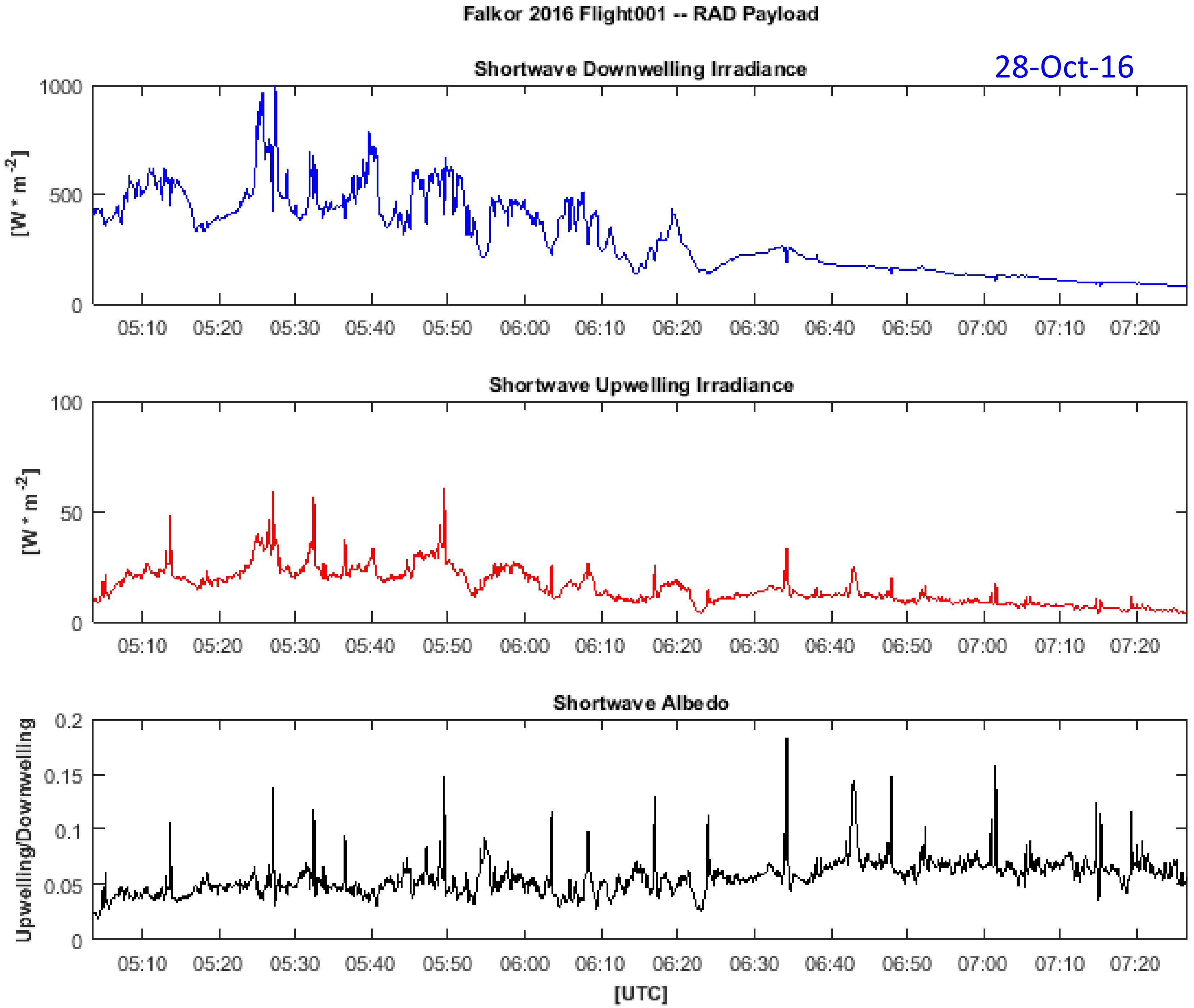


BASE payload allows for quick change between sensor payloads

GORDON AND BETTY MOORE FOUNDATION



Falkor 2016 Flight001 -- RAD Payload
28-Oct-16
IR Downwelling Irradiance
[W * m^-2]
450
440
430
420
410
400
390
05:10
05:20
05:30
05:40
05:50
06:00
06:10
06:20
06:30
06:40
06:50
07:00
07:10
07:20
IR Upwelling Irradiance
[W * m^-2]
480
460
440
420
400
05:10
05:20
05:30
05:40
05:50
06:00
06:10
06:20
06:30
06:40
06:50
07:00
07:10
07:20
[UTC]


Falkor 2016 Flight001 -- RAD Payload
28-Oct-16
Shortwave Downwelling Irradiance
[W * m^-2]
1000
500
0
05:10
05:20
05:30
05:40
05:50
06:00
06:10
06:20
06:30
06:40
06:50
07:00
07:10
07:20
Shortwave Upwelling Irradiance
[W * m^-2]
100
50
0
05:10
05:20
05:30
05:40
05:50
06:00
06:10
06:20
06:30
06:40
06:50
07:00
07:10
07:20
Shortwave Albedo
Upwelling/Downwelling
0.2
0.15
0.1
0.05
0
05:10
05:20
05:30
05:40
05:50
06:00
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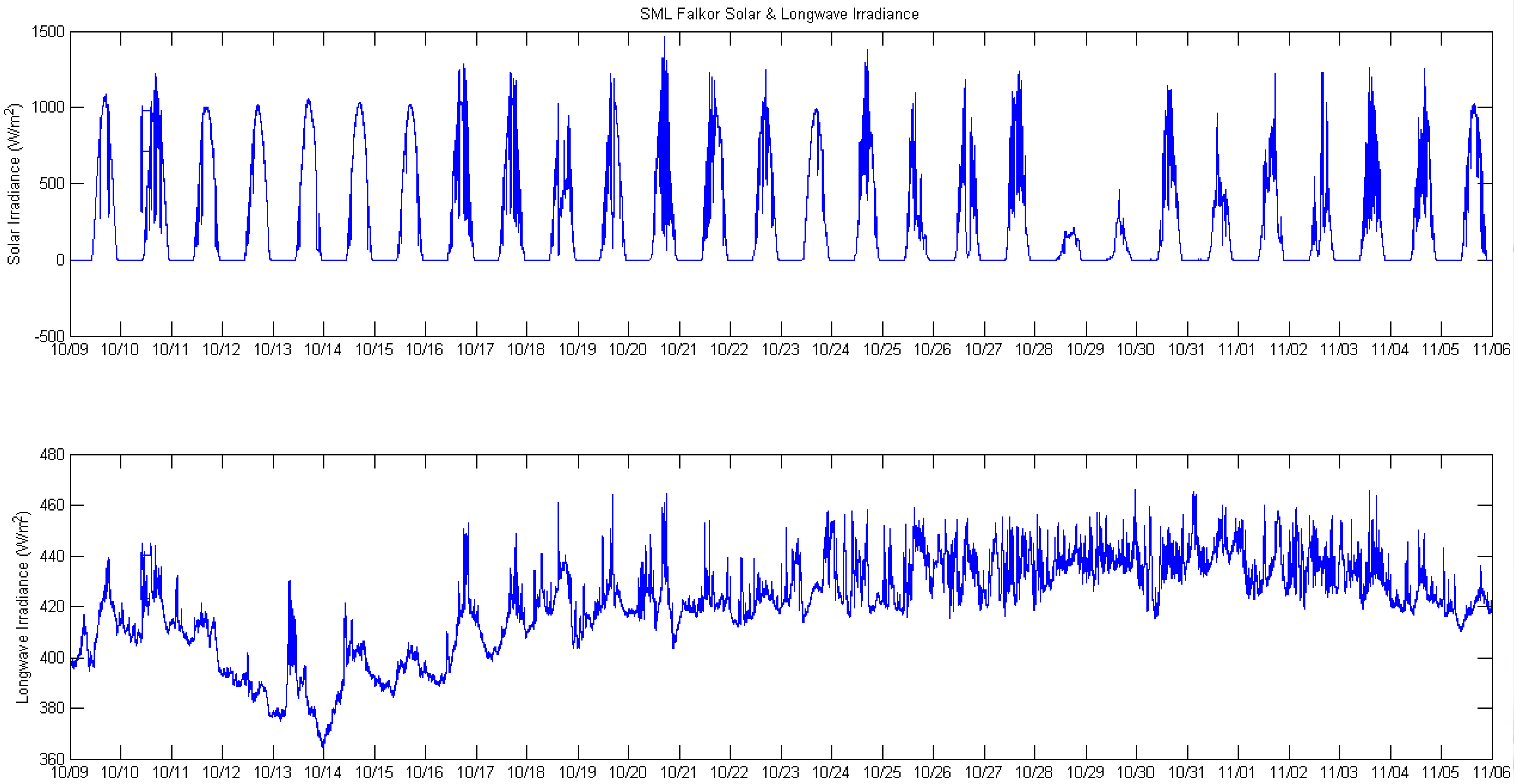
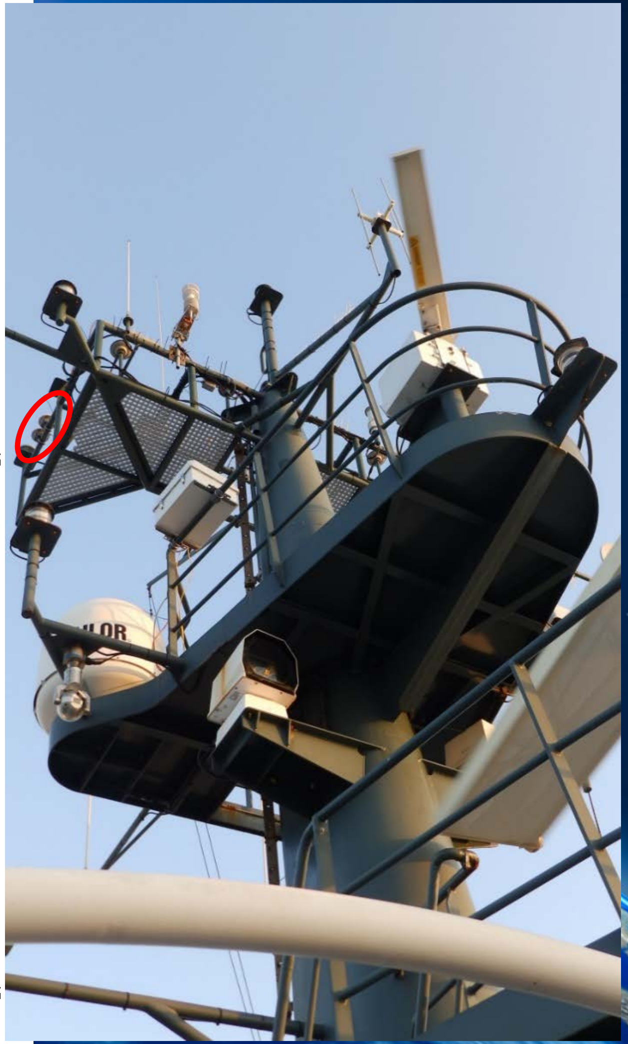
06:50
07:00
07:10
07:20
[UTC]

Solar/IR Radiation Data

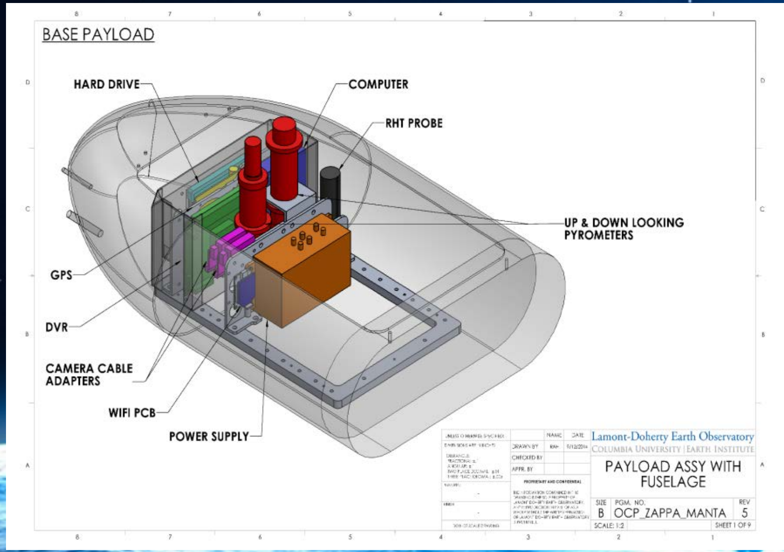
Overview



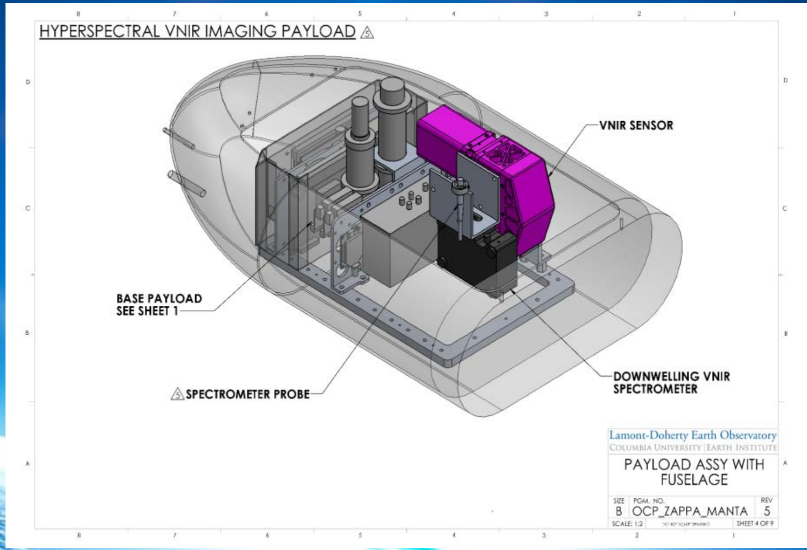


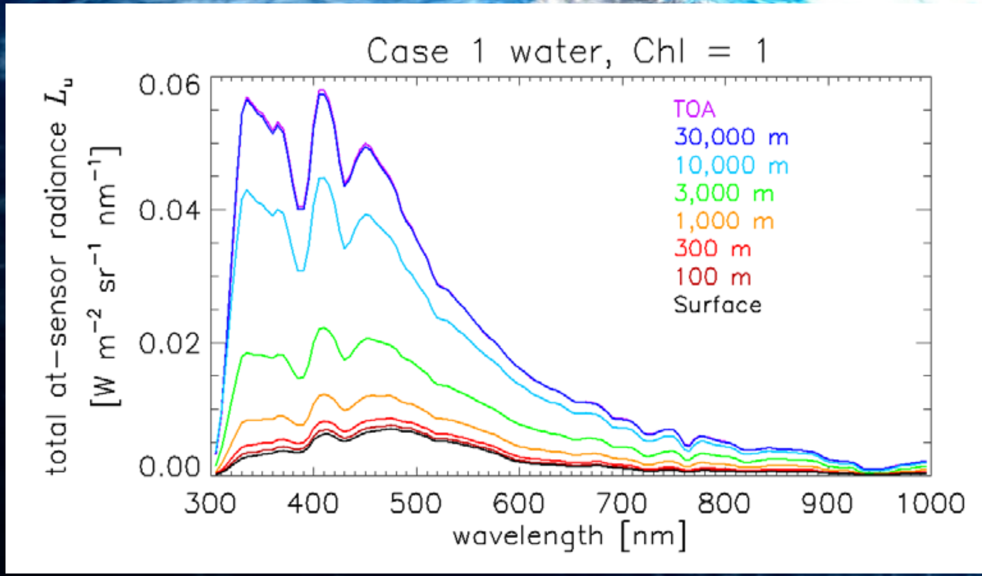
Hyperspectral Payload Development

BASE Payload

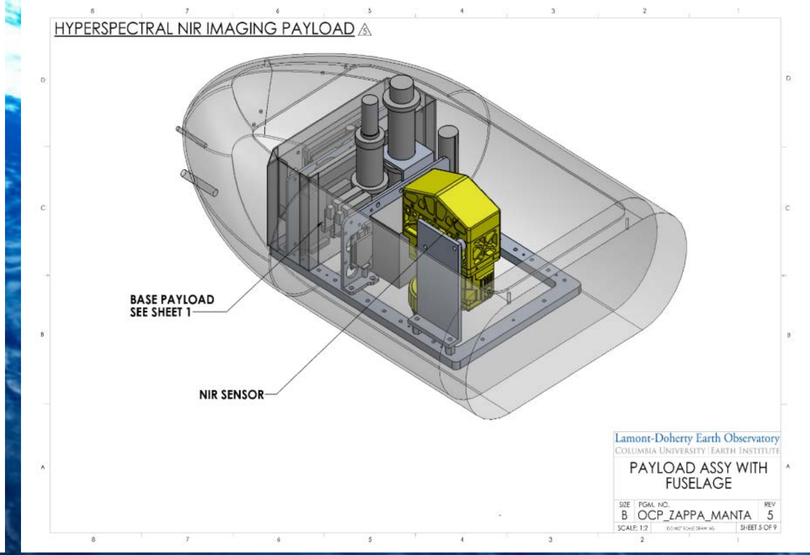


VNIR Module



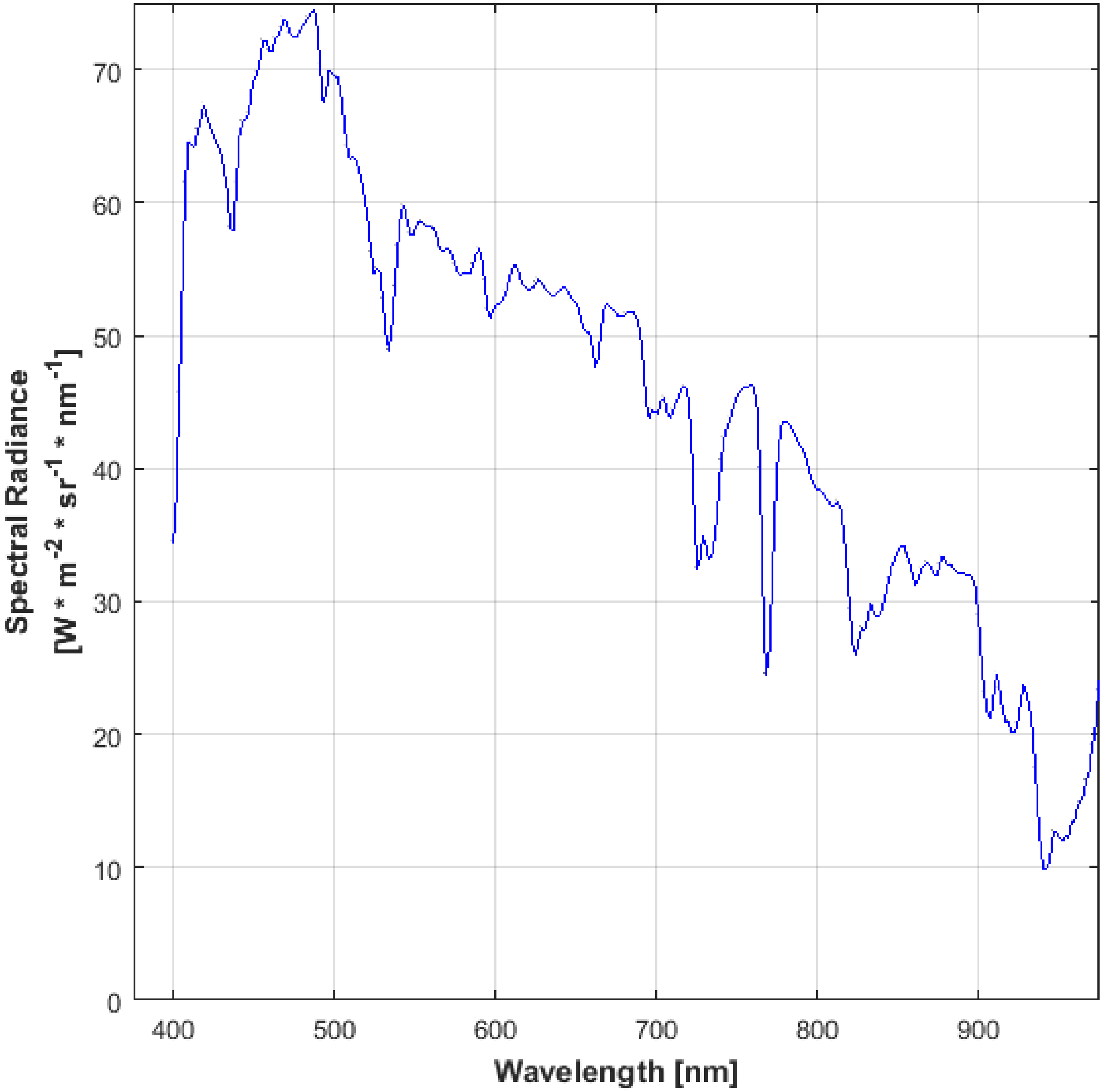


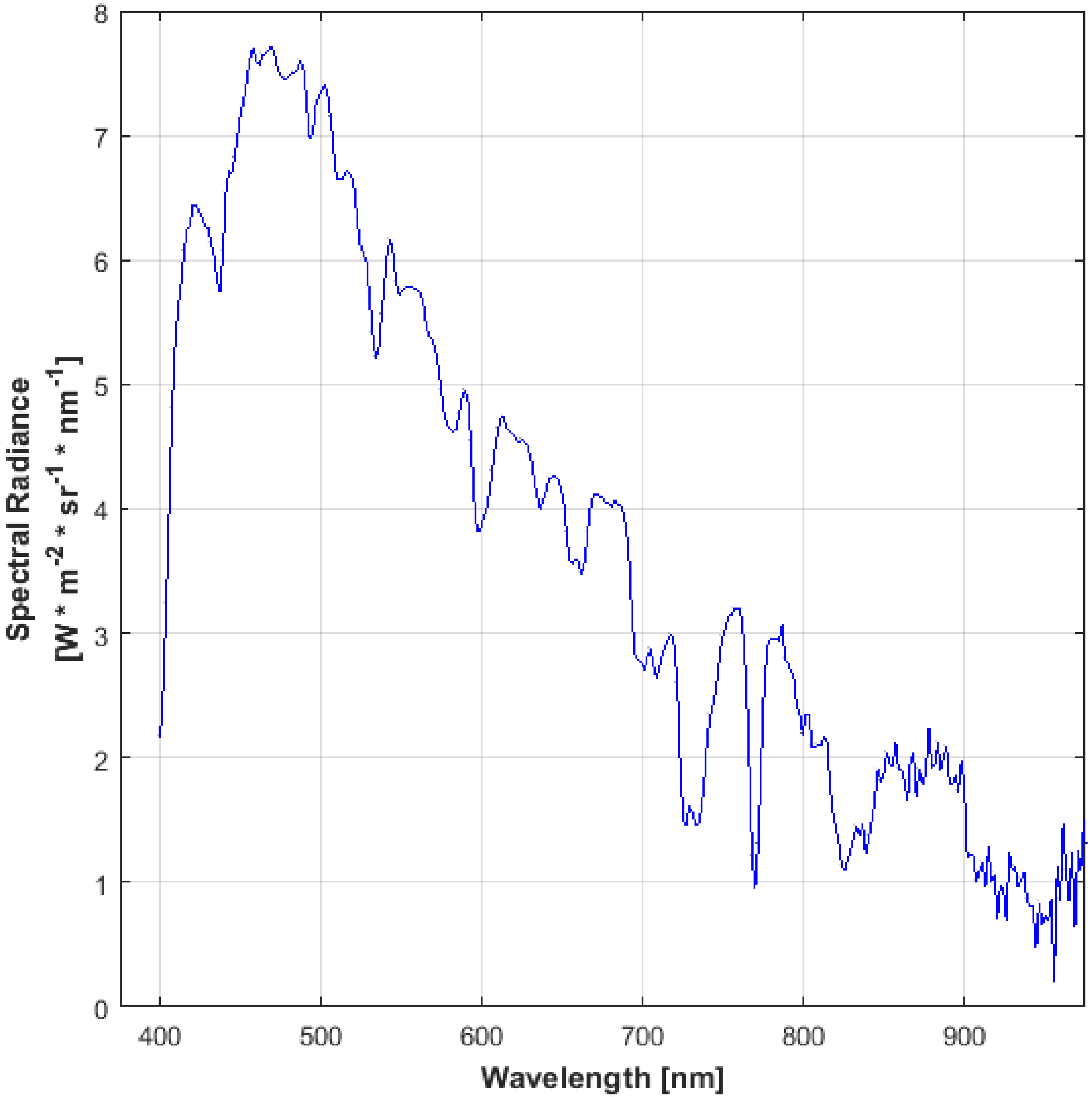
NIR Module



VNIR Payload – F11 – F12

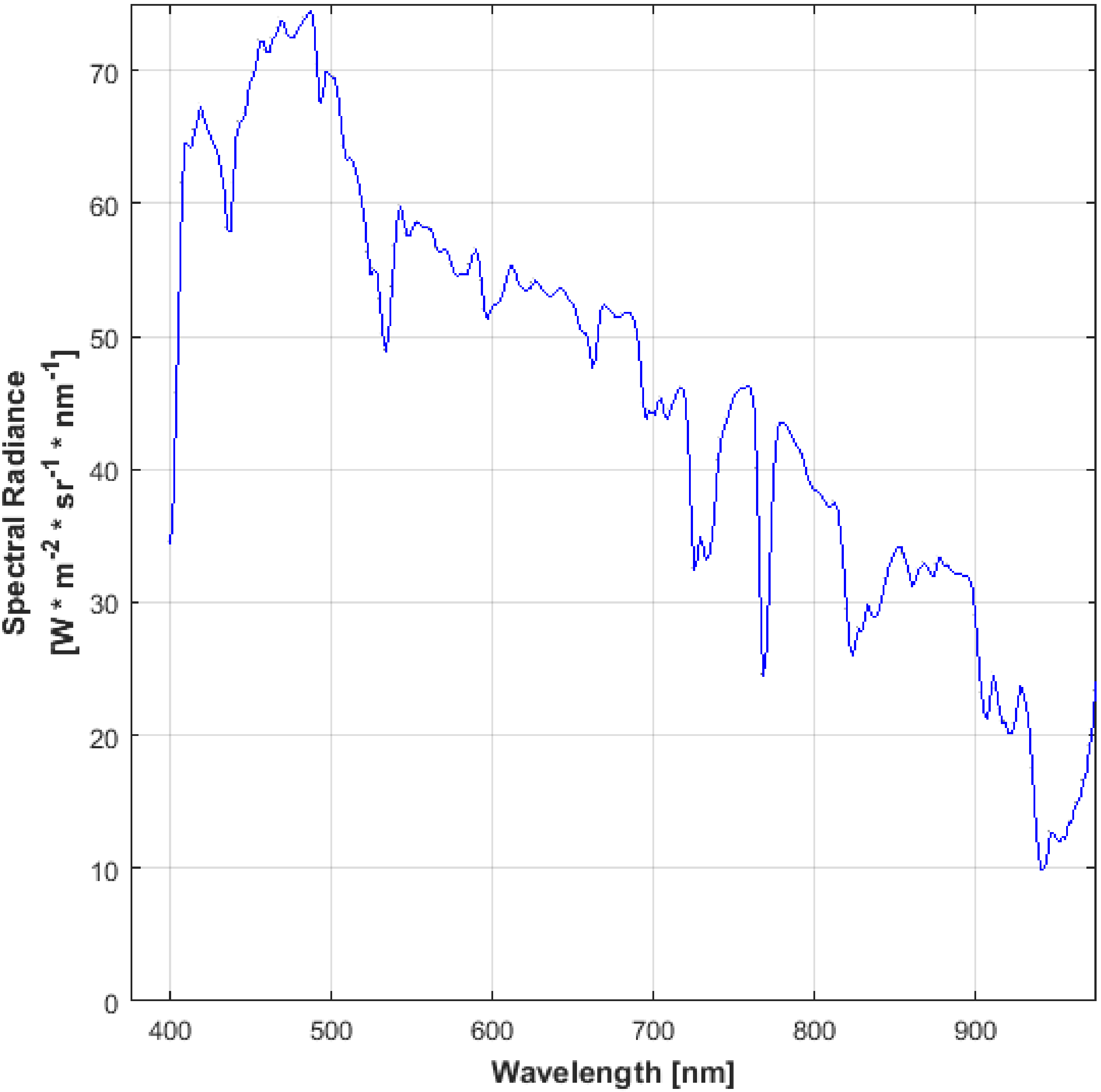
6-Nov-16

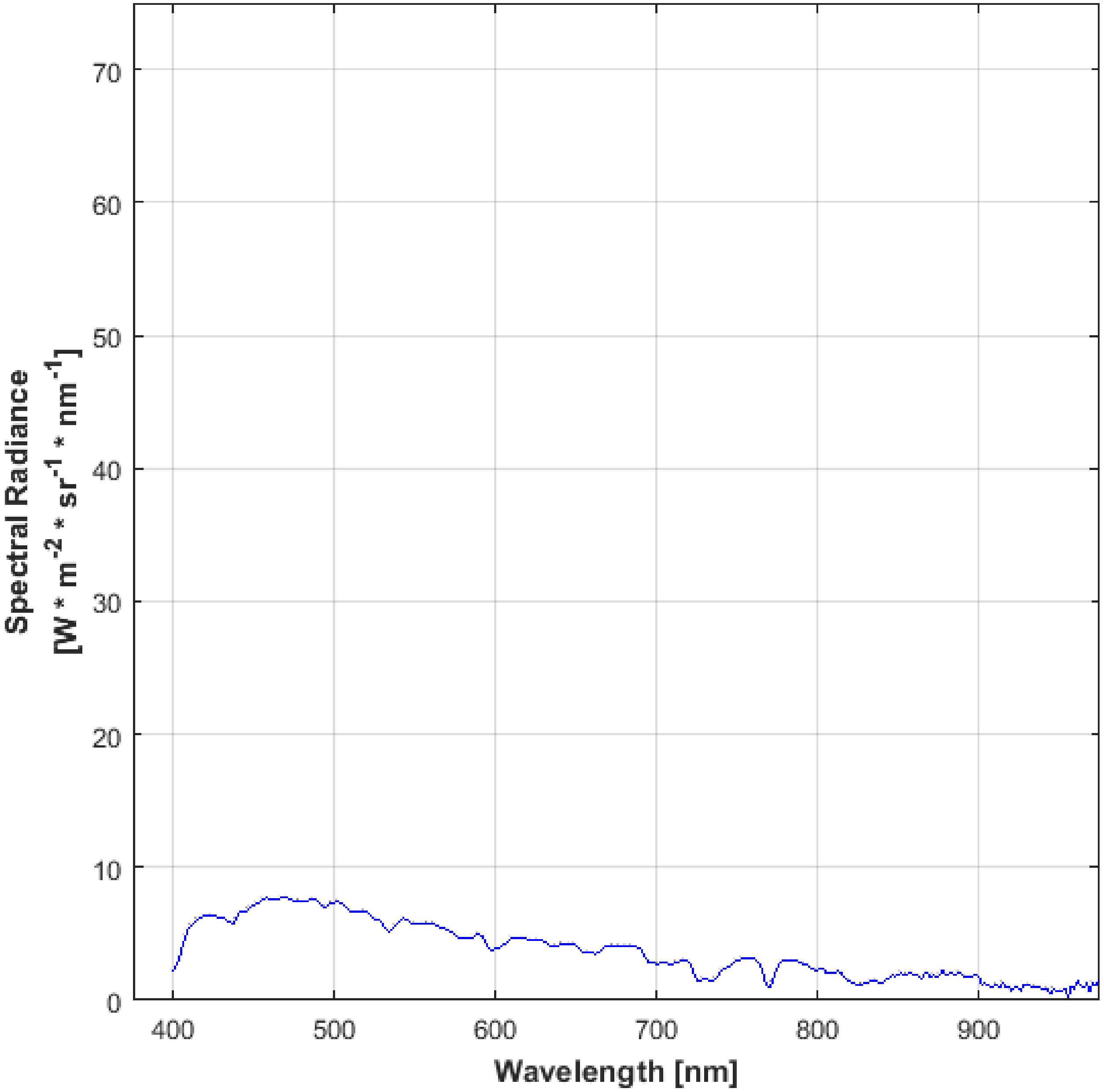




VNIR Payload – F11 – F12

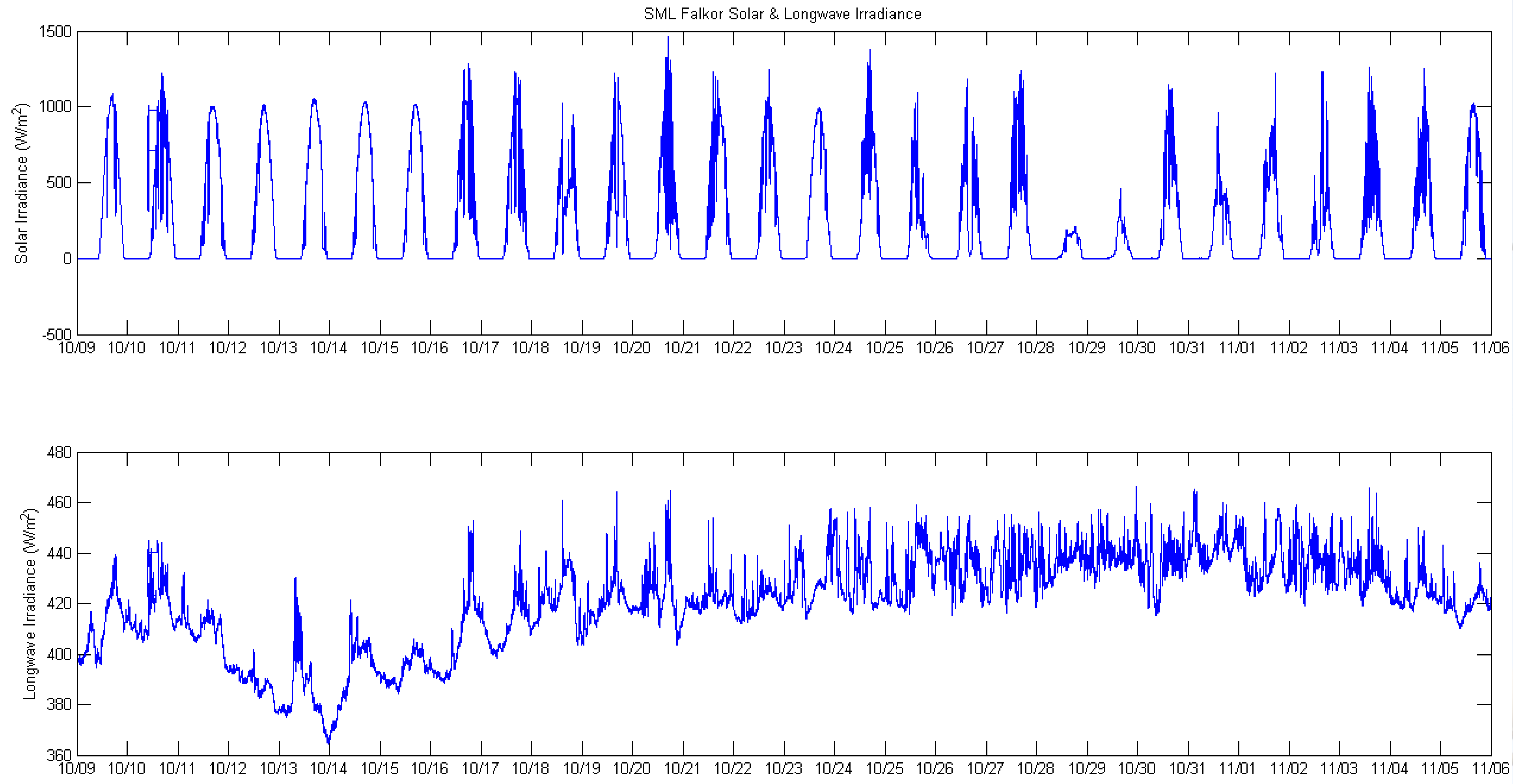
6-Nov-16

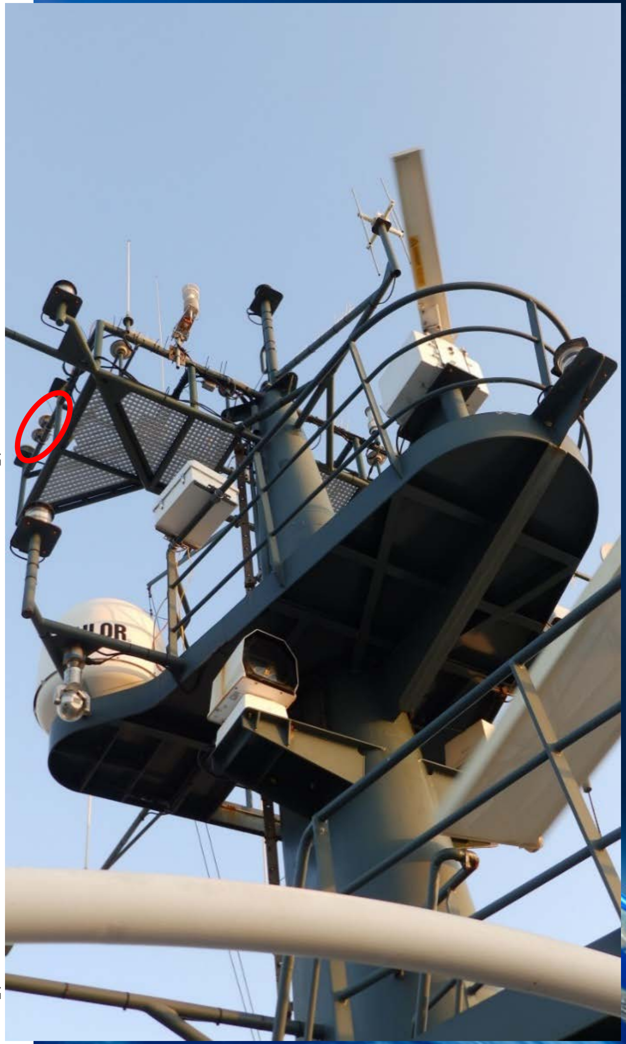




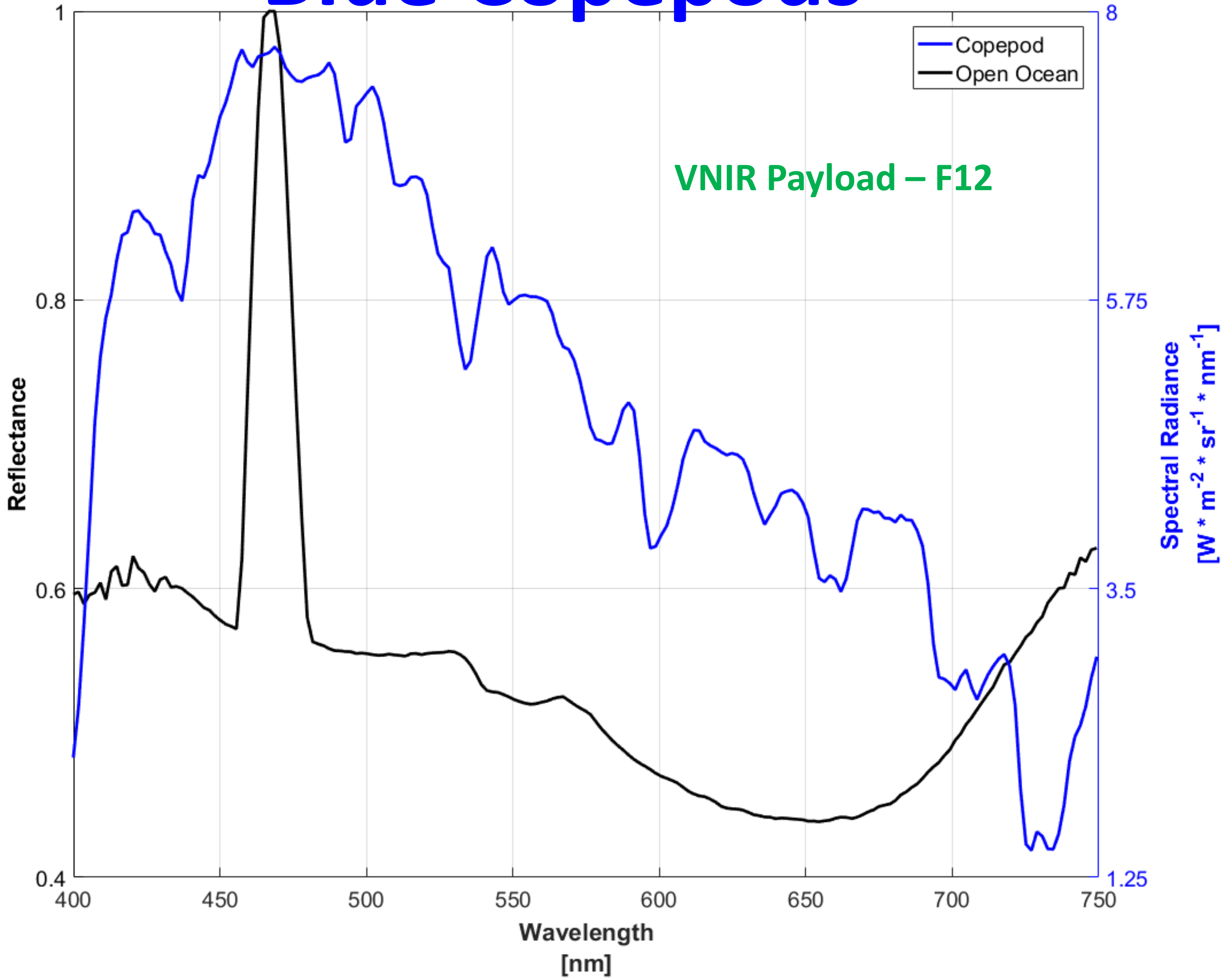
Solar/IR Radiation Data

Overview

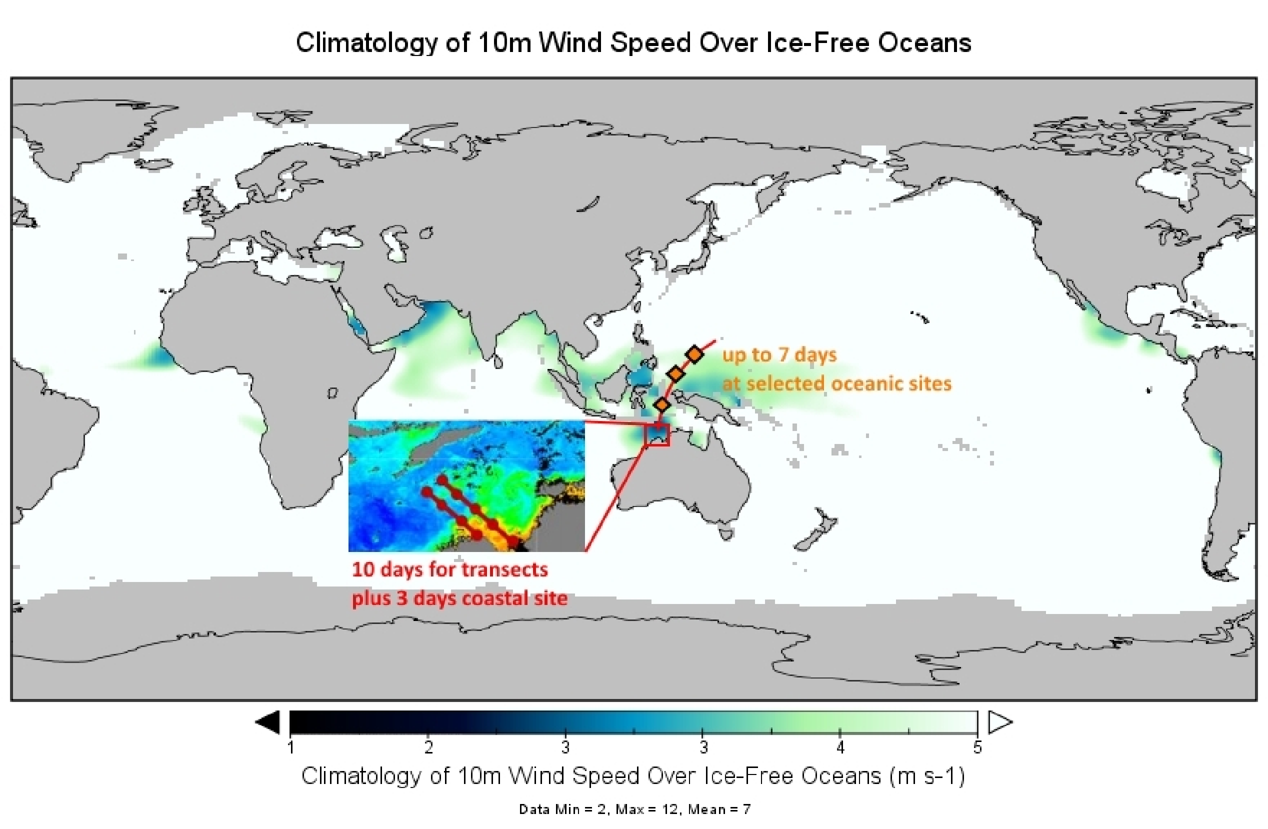




Blue Copepods



Current Directions – R/V Falkor



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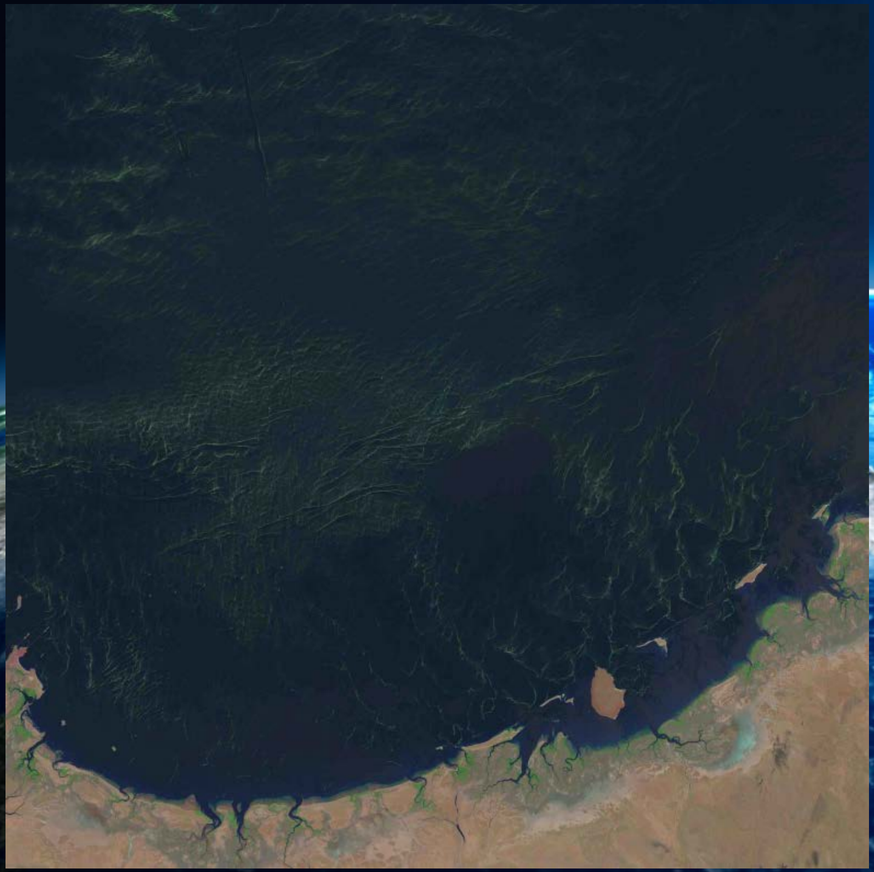
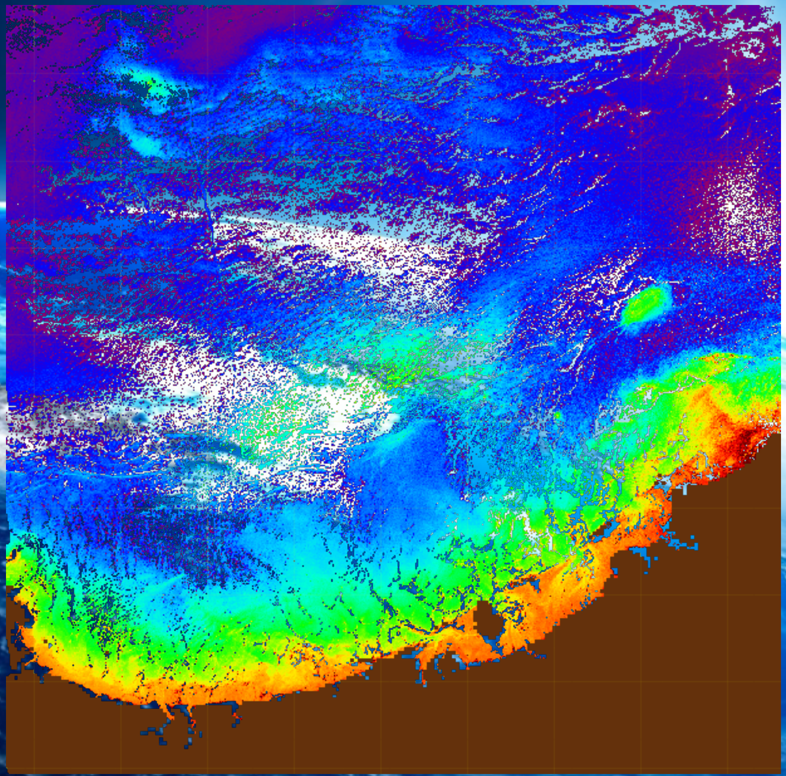
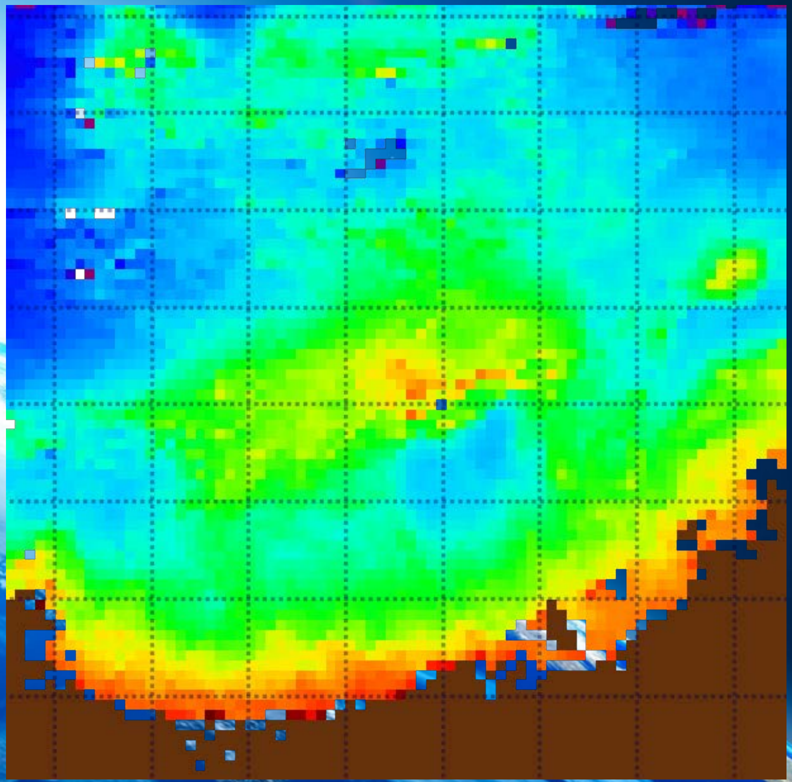
Current Directions – R/V Falkor

Dense internal wave field



- Effects of biogenic slicks on albedo, near-surface heat flux, diurnal warm-layer processes and mixing.





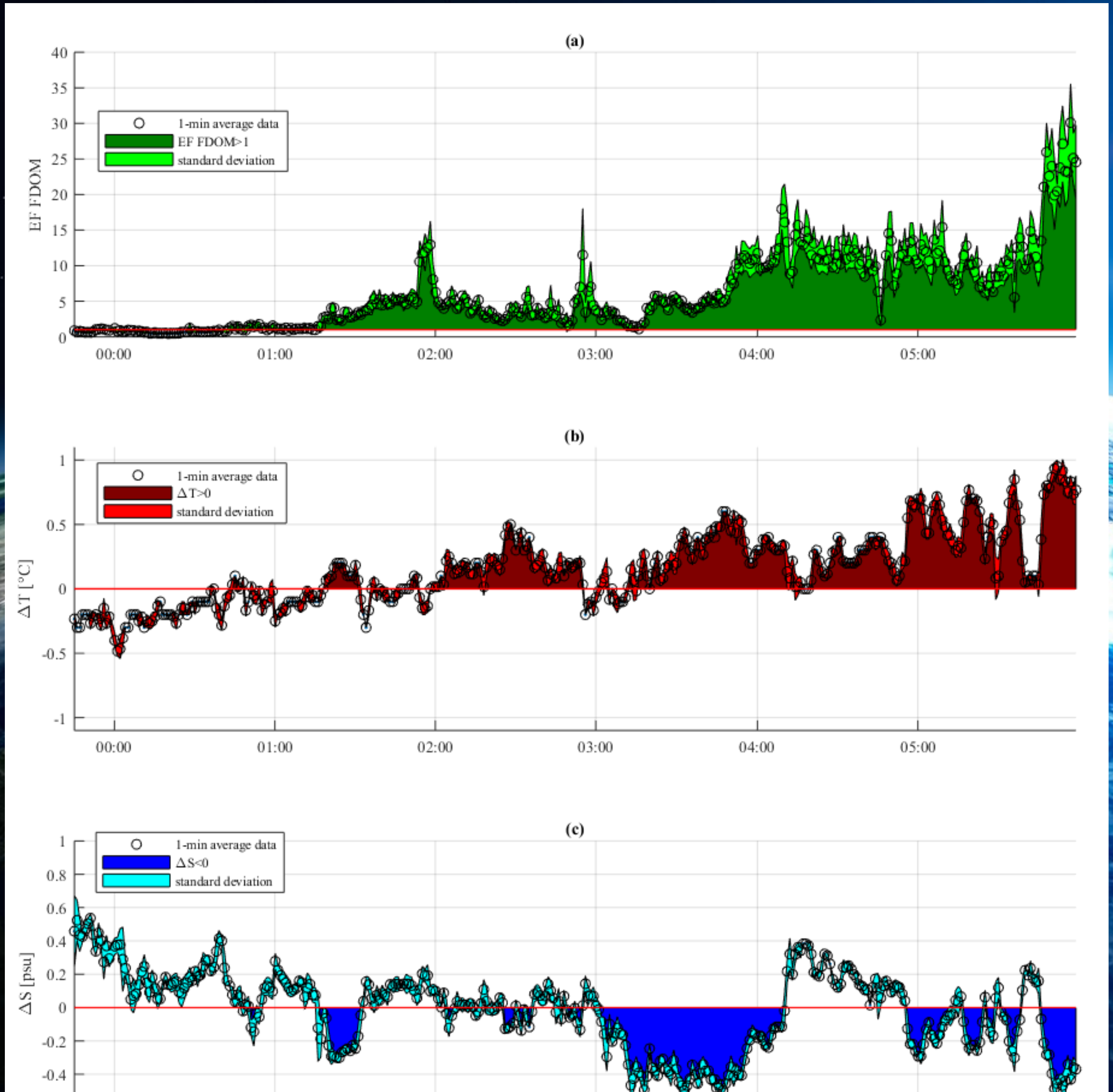
(Top) True color image captured by the Landsat satellite on November 17, 2014, of the coast of Northwestern Australia, east of Point Samson. (Bottom Left) 30 m resolution chlorophyll map obtained from the Landsat data. The high albedo from the dense surface slicks trigger the cloud mask (white). (Bottom Right) MODIS Aqua map of chlorophyll for the same day.

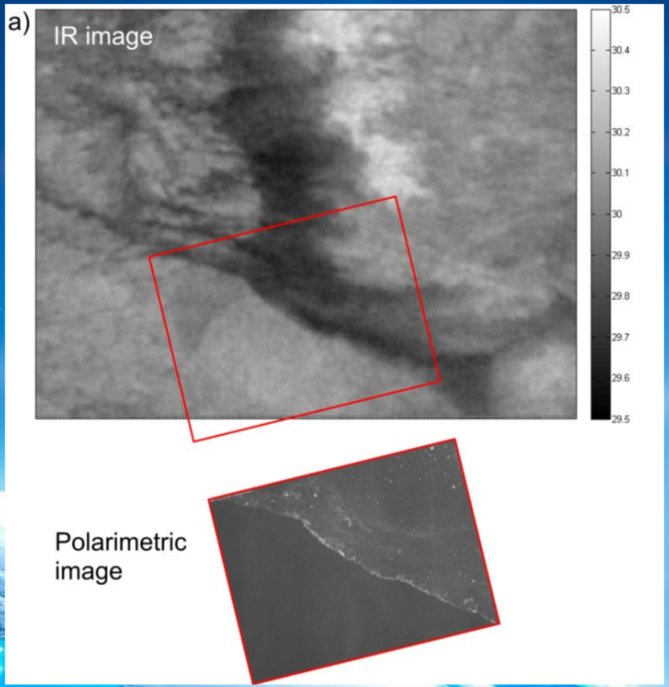
Current Directions – R/V Falkor

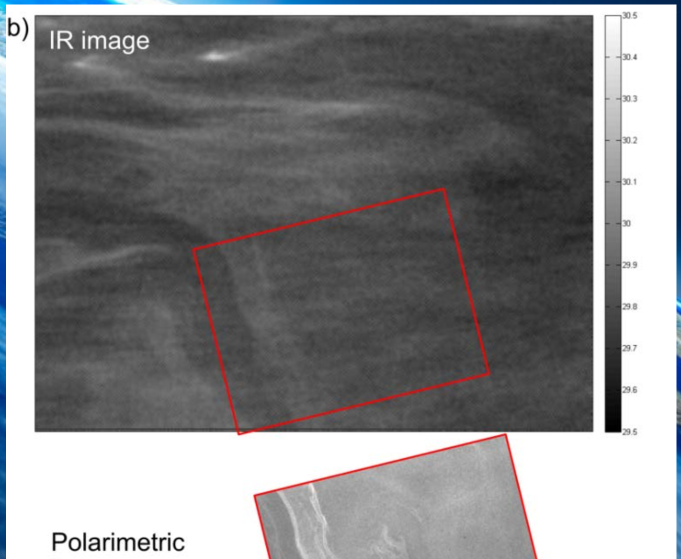
Trichodesmium

Trichodesmium

Current Directions – R/V Falkor



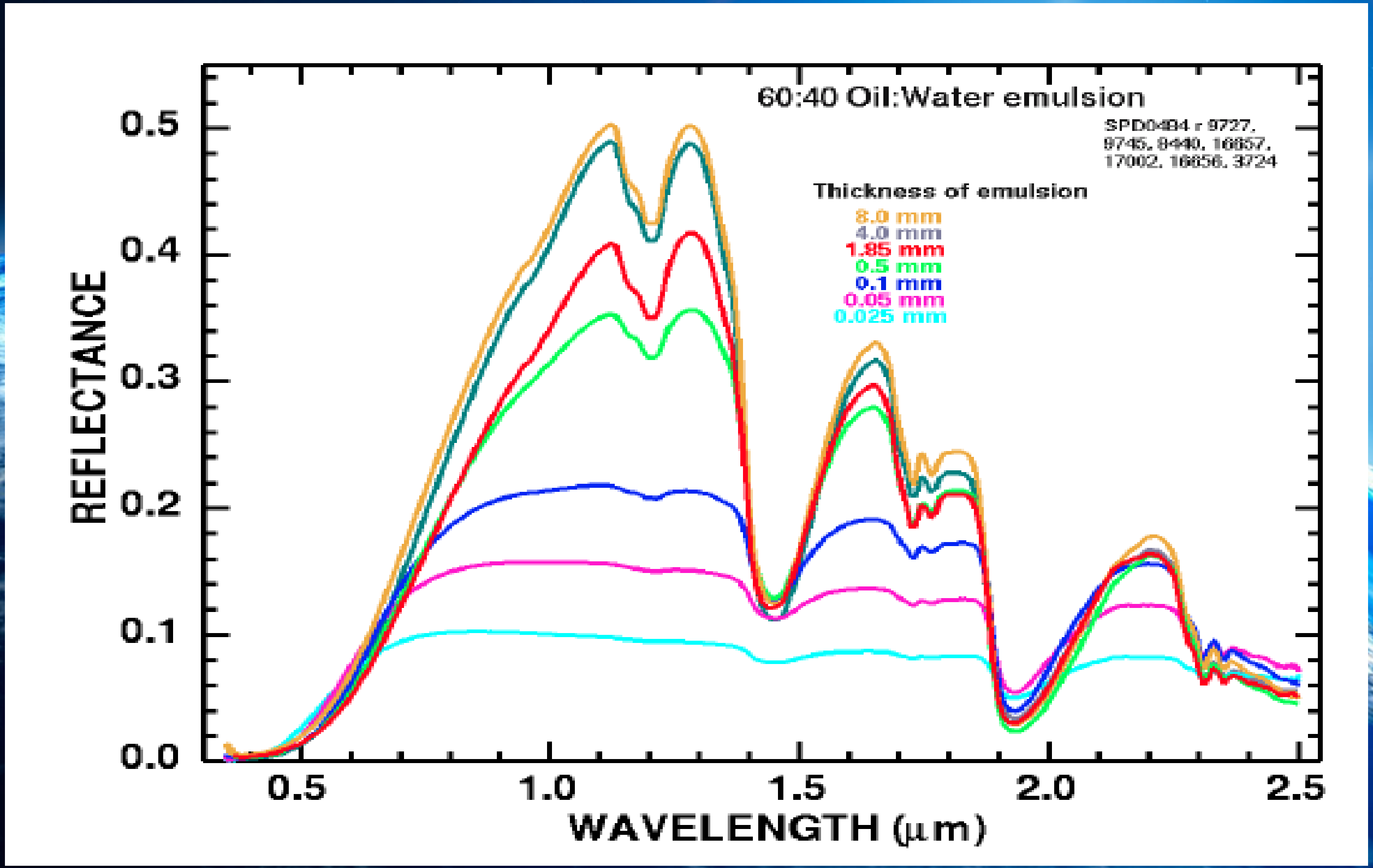


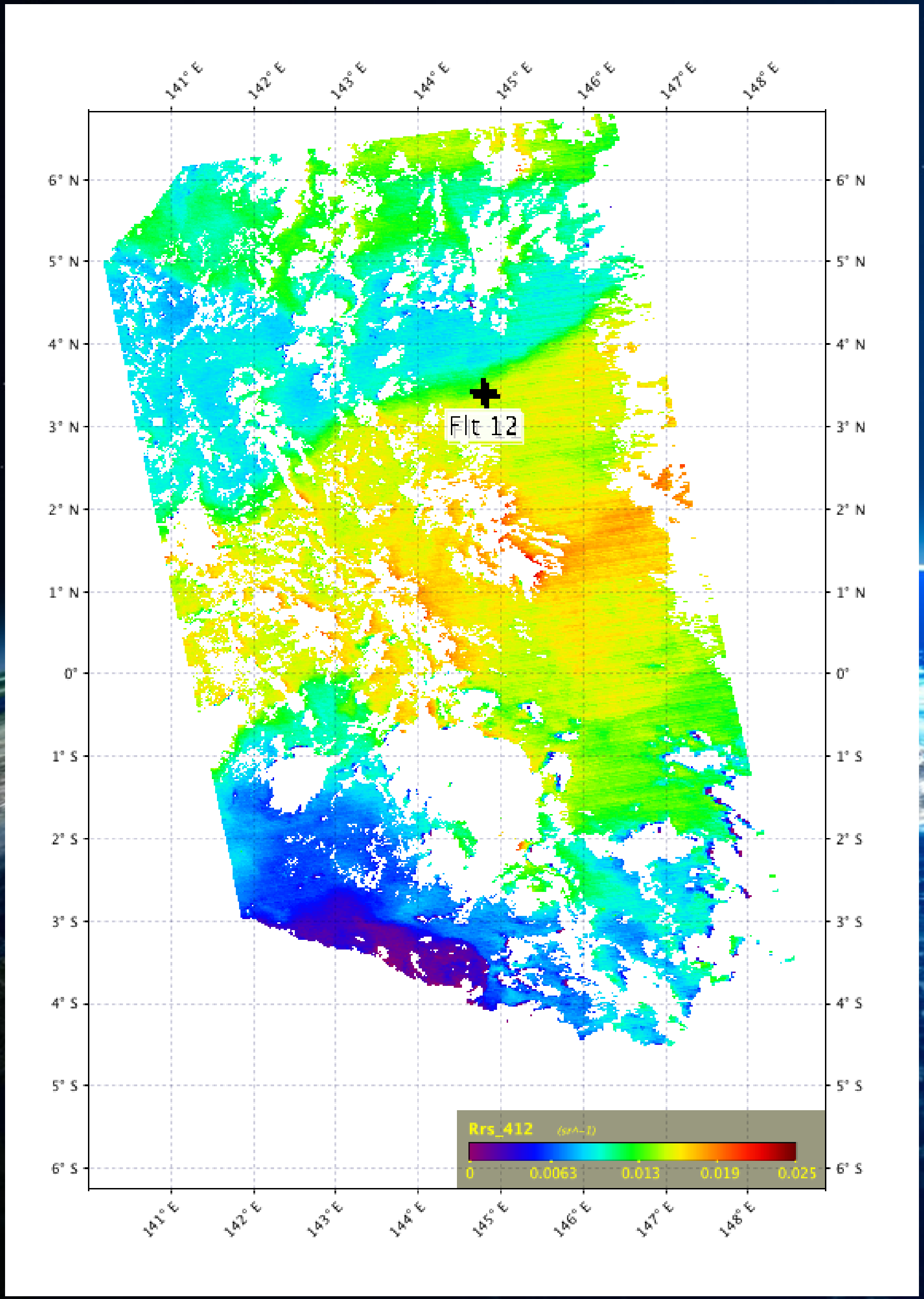


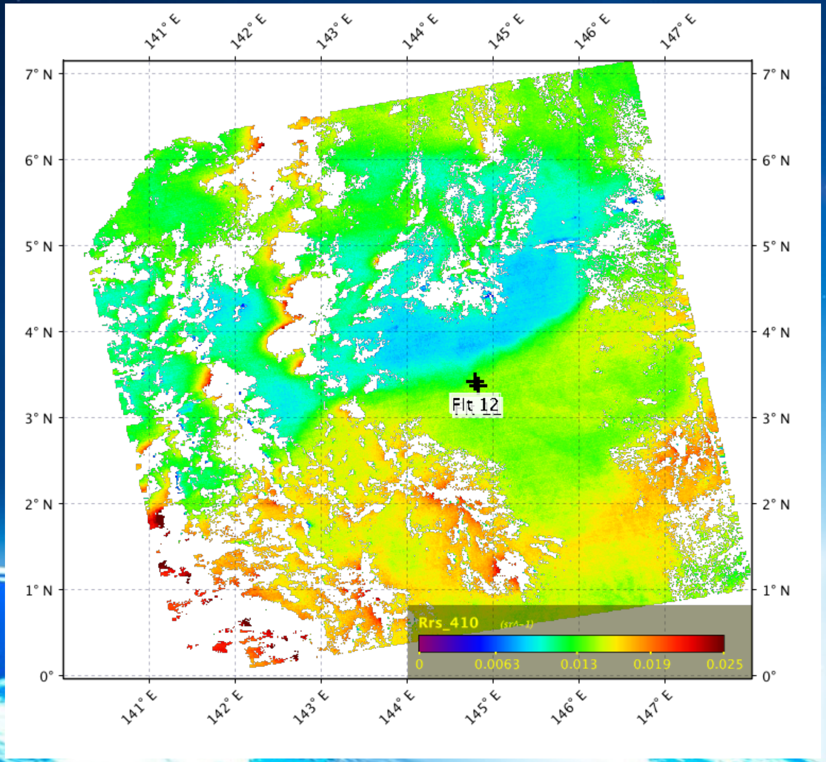
Current Directions – R/V Falkor

Trichodesmium

Current Directions – R/V Falkor

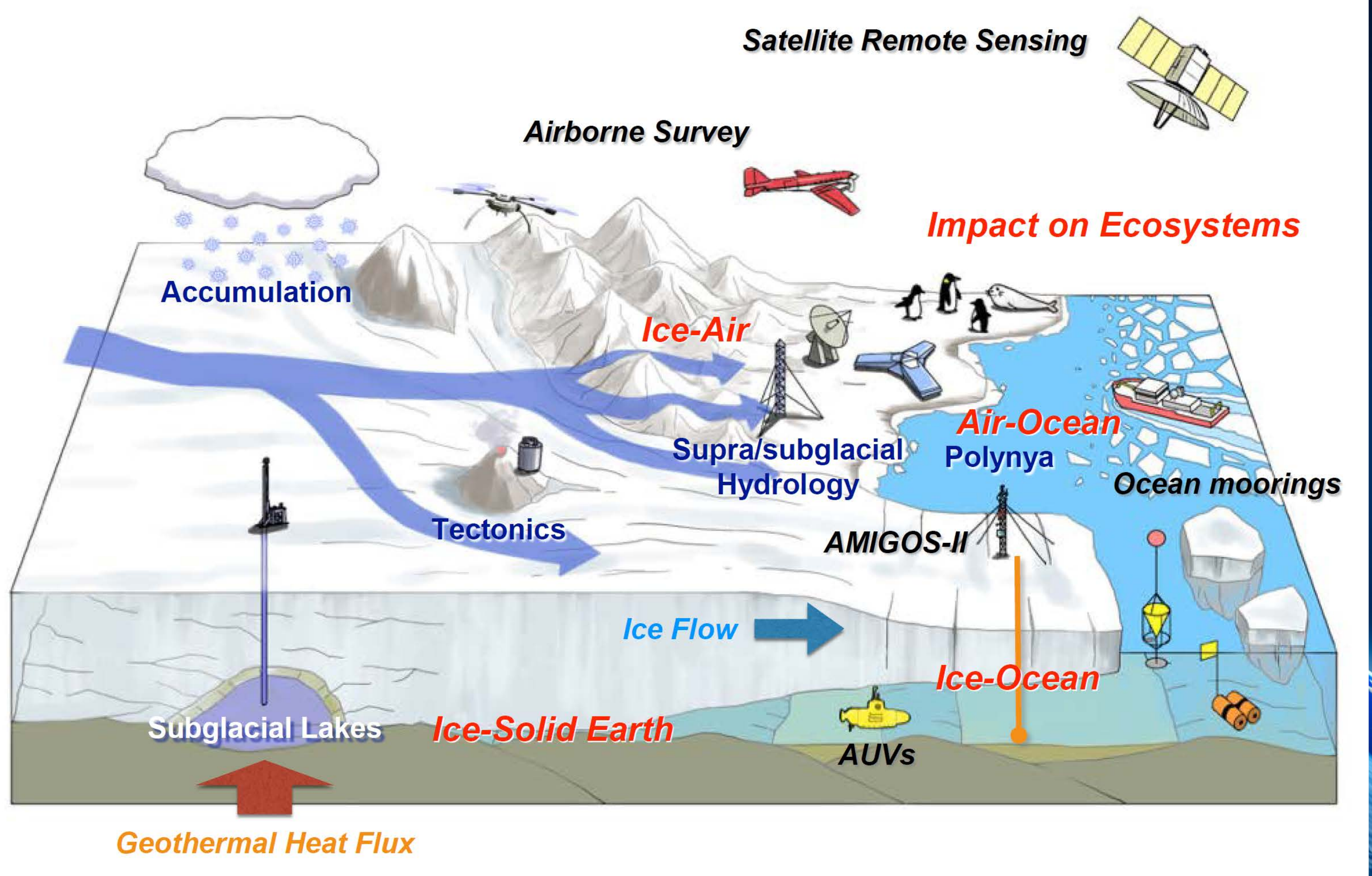






Rrs = Lu/Ed
where
Rrs is remote sensing Reflectance in per steradian;
Lu is the upwelling Radiance in W/m2/Str
Ed is the downwelling Irradiance in W/m2.

Aqua and VIIRS

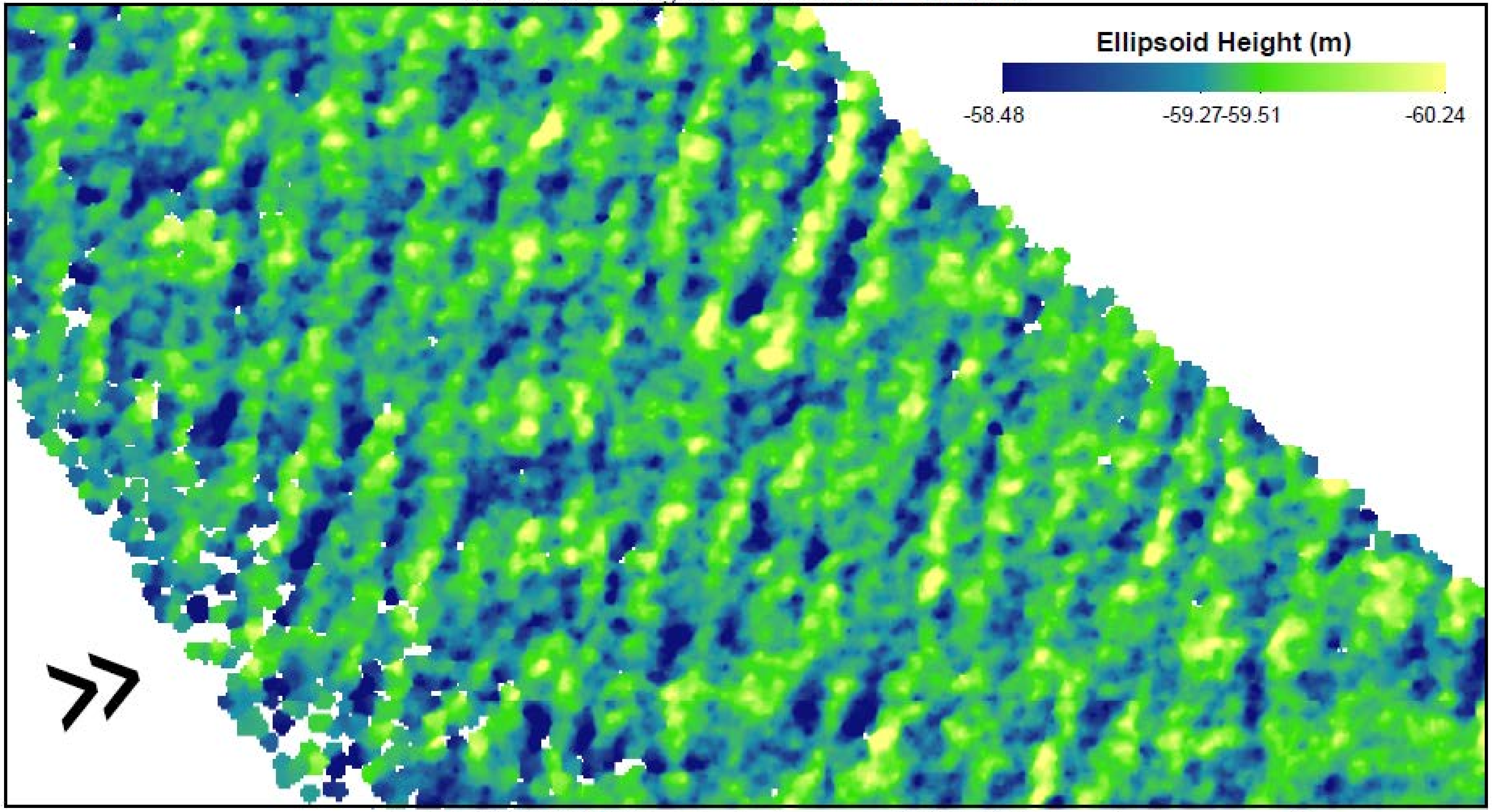


Satellite Remote Sensing
Airborne Survey
Impact on Ecosystems
Accumulation
Ice-Air
Air-Ocean
Supra/subglacial
Hydrology
Polynya
Ocean moorings
Tectonics
AMIGOS-II
Ice Flow
Ice-Ocean
Subglacial Lakes
Ice-Solid Earth
AUVs
Geothermal Heat Flux

R/V Araon

Surface Ellipsoid Height from LIDAR Over Waves - IDW Grid

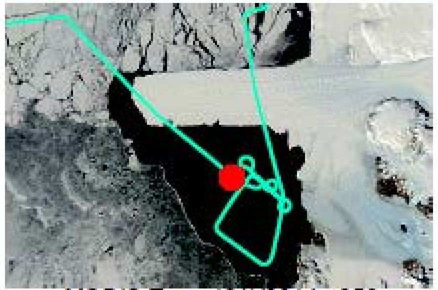
Antarctica 1 - Flight 6 - Dec. 1 2014 - 08:49:23



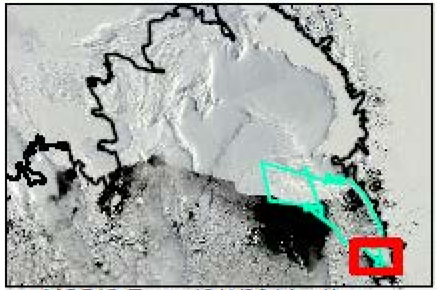
50
Meters

Angle gate filter applied
(only +/- 10 degrees from nadir)

Grid Method: Inverse Distance Weighted
Cell Size: 1m
Search Radius: 3m



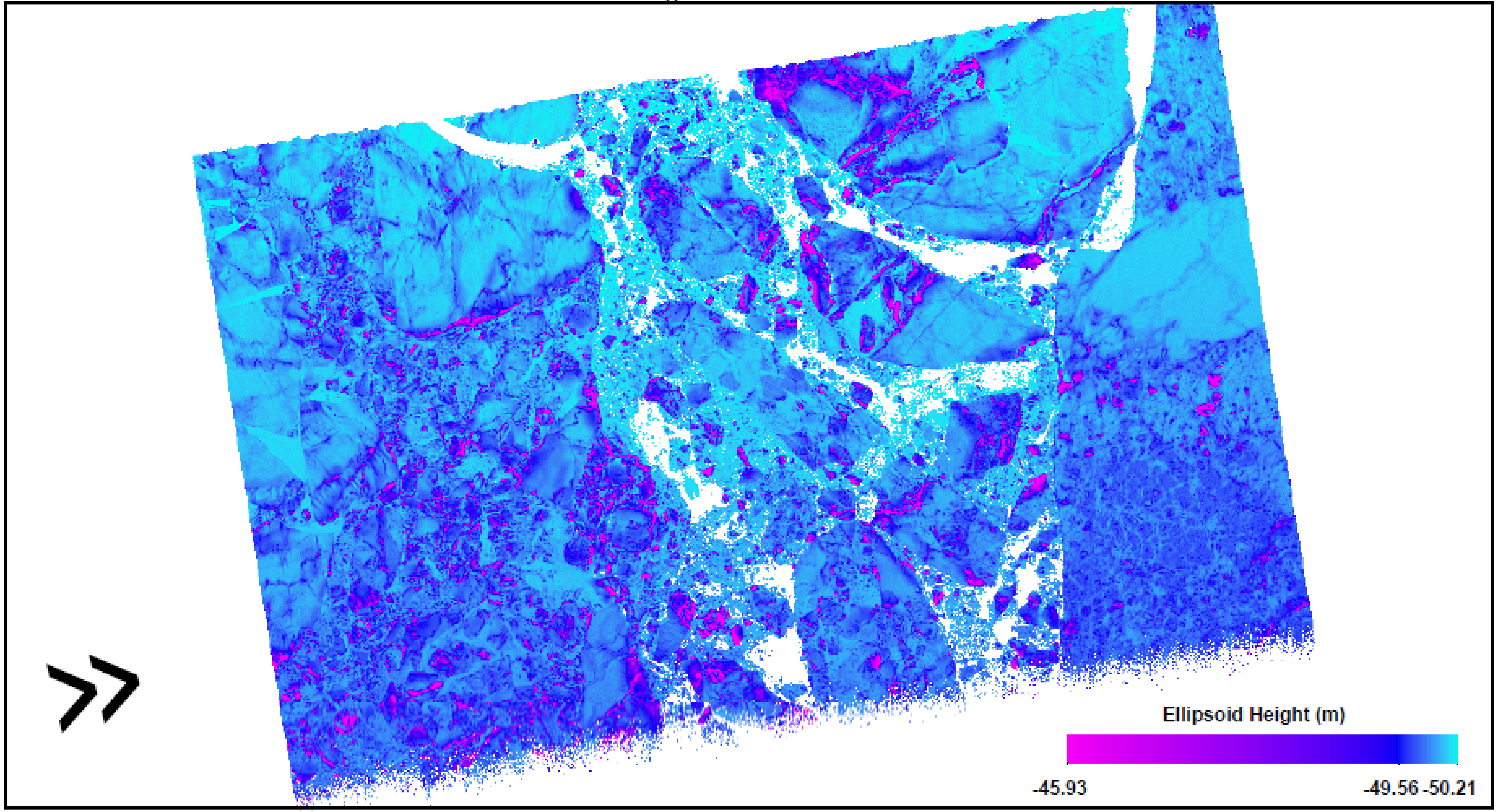
MODIS Terra 12/1/2014 - 250m



MODIS Terra 12/1/2014 - 1km

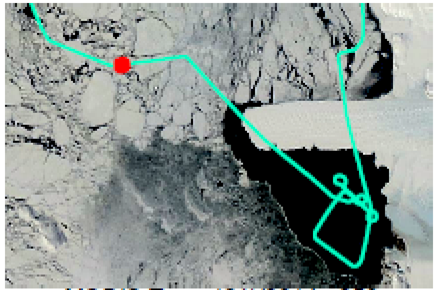
Surface Ellipsoid Height from LIDAR Over Sea Ice - IDW Grid

Antarctica 1 - Flight 6 - Dec. 1 2014 - 08:26:23

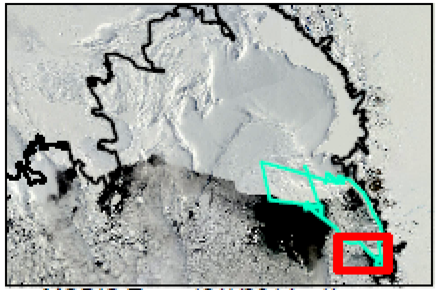


200
Meters

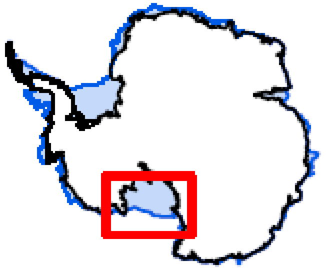
Grid Method: Inverse Distance Weighted
Cell Size: 20cm
Search Radius: 80cm



MODIS Terra 12/1/2014 - 250m



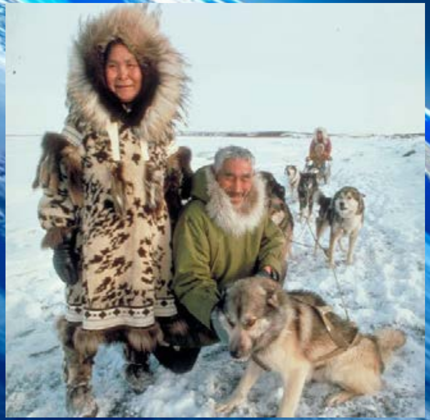
MODIS Terra 12/1/2014 - 1km



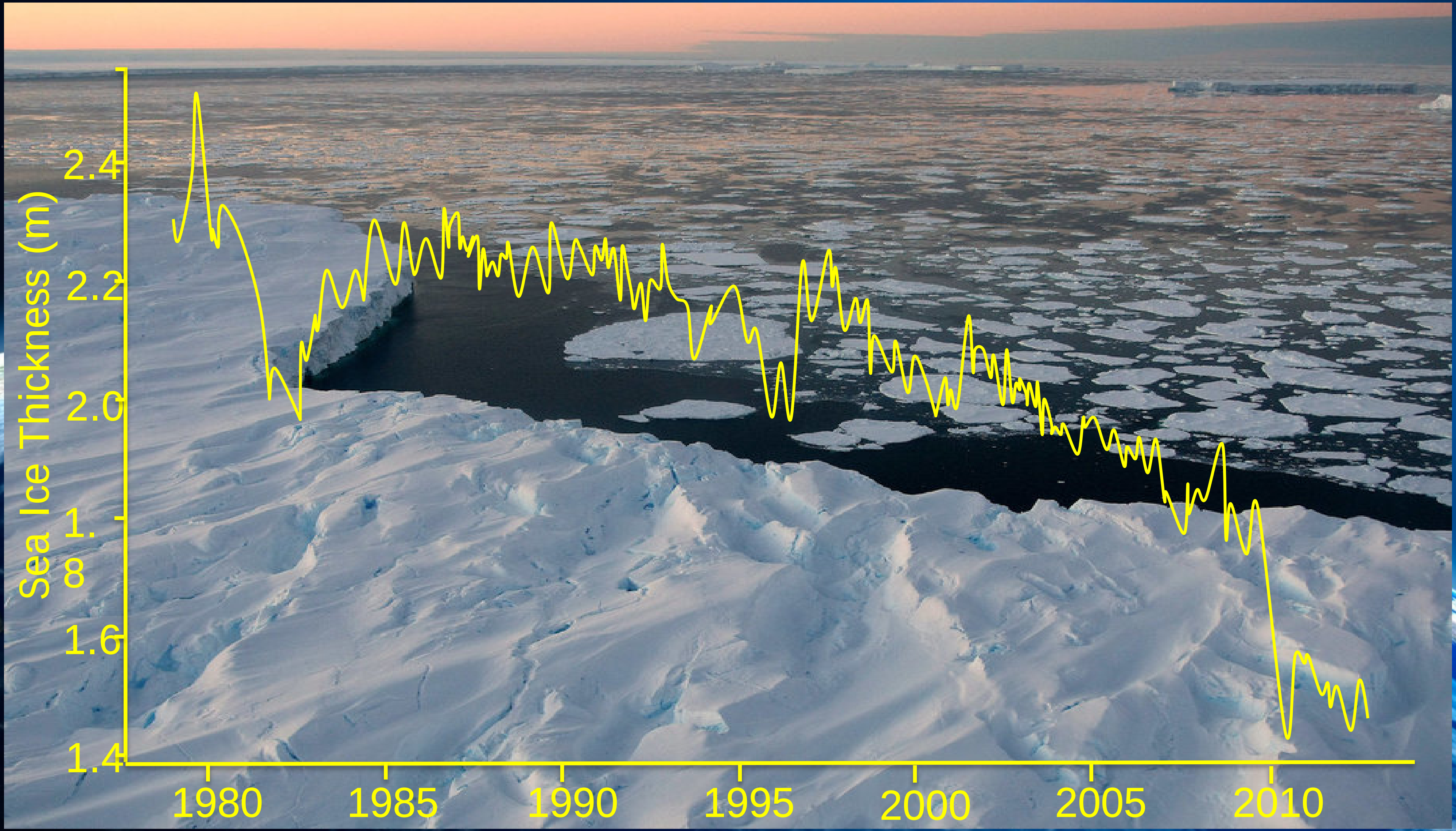
Bridging the Scientific and Indigenous Communities to Study Sea Ice Change in Arctic Alaska

Christopher Zappa (LDEO), Andy Mahoney (UAF), Alex Whiting (NVK), Sarah Betcher (FNF)



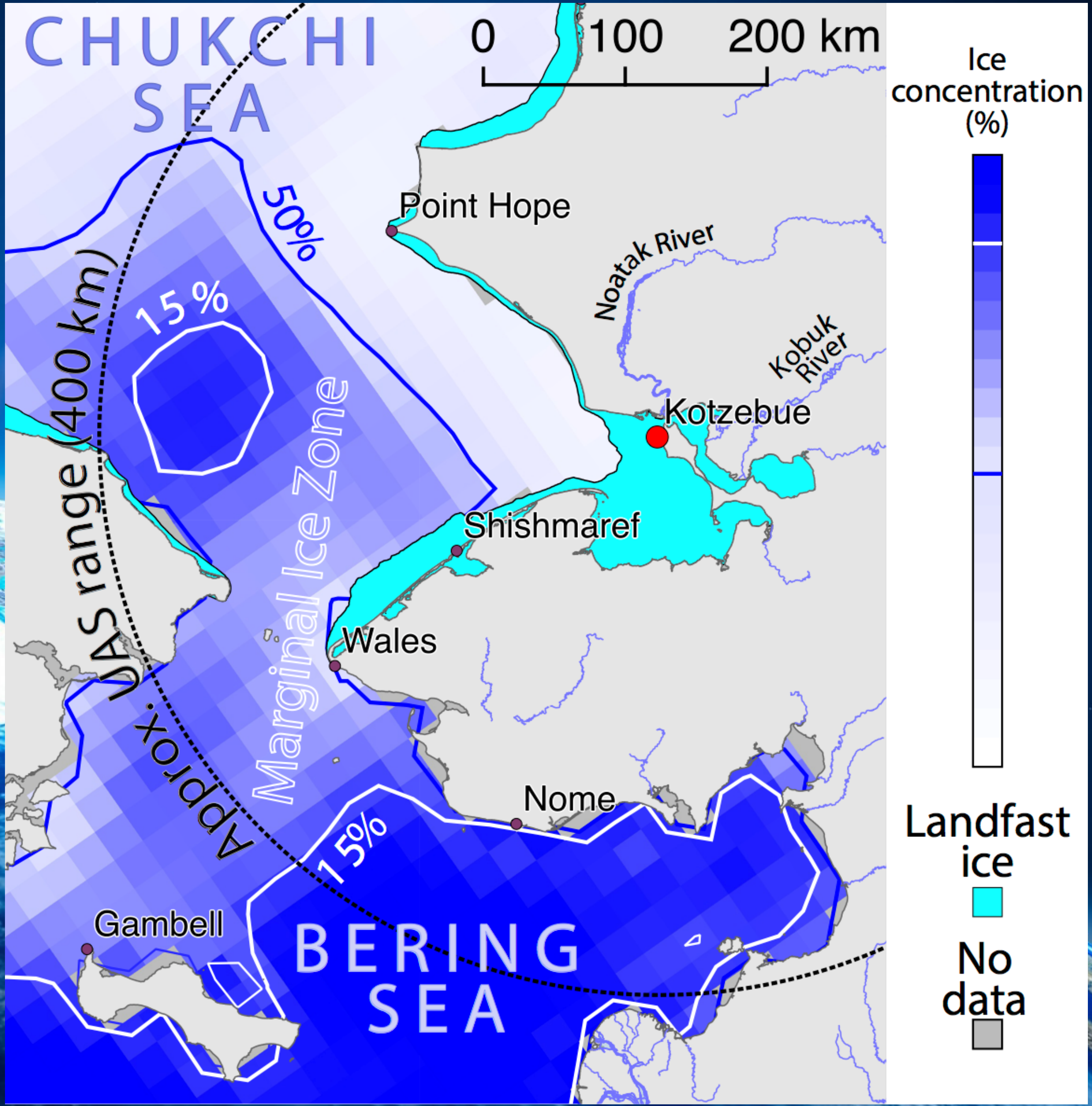



Sea Ice is Thinning



Consequences of Sea Ice Change

0 25 50 km
Noatak River
Kivalina
Noatak
CHUKCHI SEA
Sheshalik
Kotzebue
Hotham Inlet
Kiana
Noorvik
Kobuk R.
Selawik
Espenberg
KOTZEBUE SOUND
Deering
Buckland



CHUKCHI SEA
0 100 200 km
Ice concentration (%)
50%
15 %
Point Hope
Noatak River
Kobuk River
Kotzebue
Shishmaref
Wales
Approx. UAS range (400 km)
Marginal Ice Zone
Nome
15%
Gambell
BERING SEA
Landfast ice
No data

Project Goals

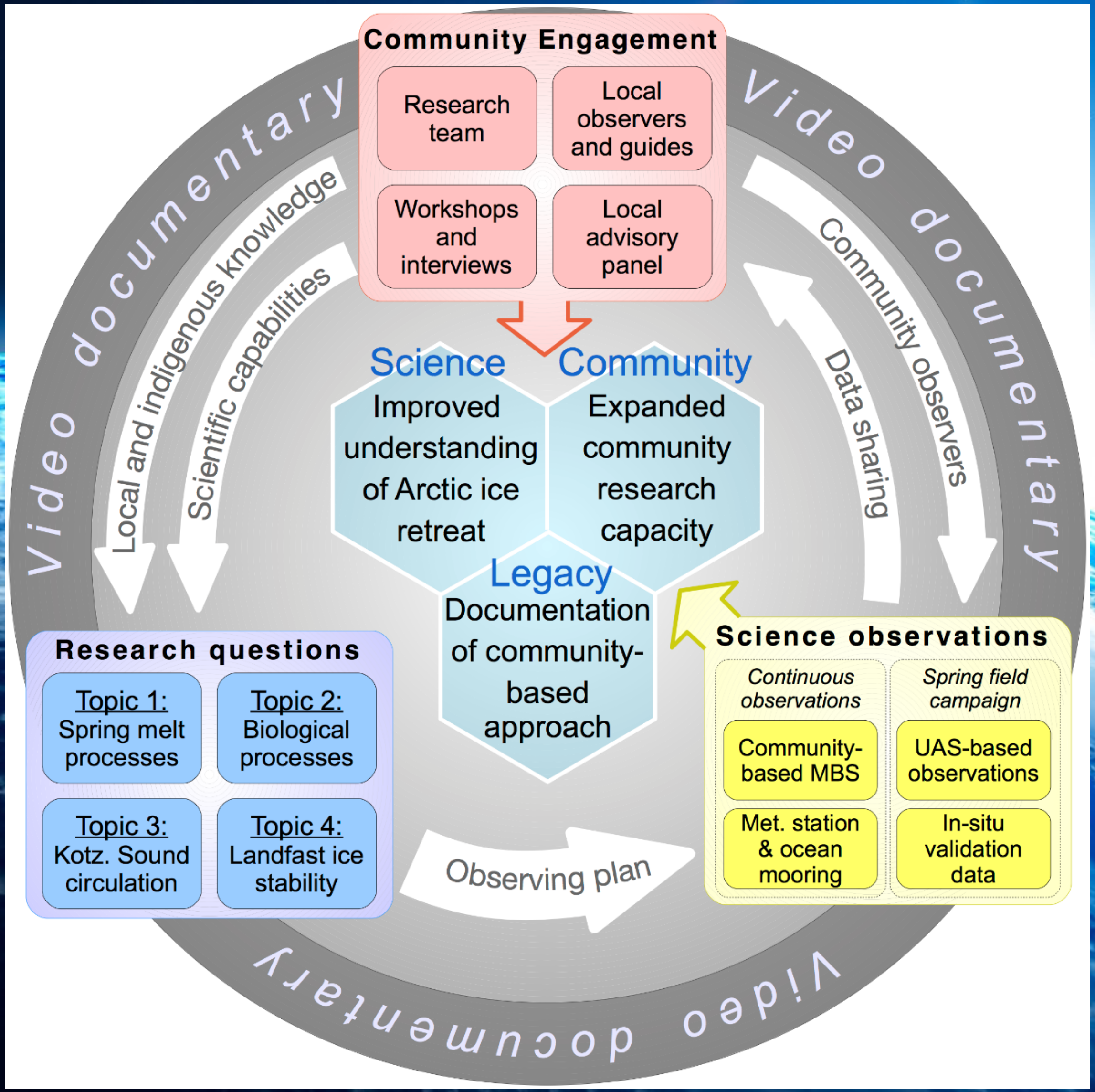
- Understand sea ice dynamics and how it is changing with a warming climate

- Bridge scientific & indigenous knowledge to study changes in sea ice that will lead to predictive models for:
    - Sea ice loss
    - Impact on ocean life
    - Impact on land mammals

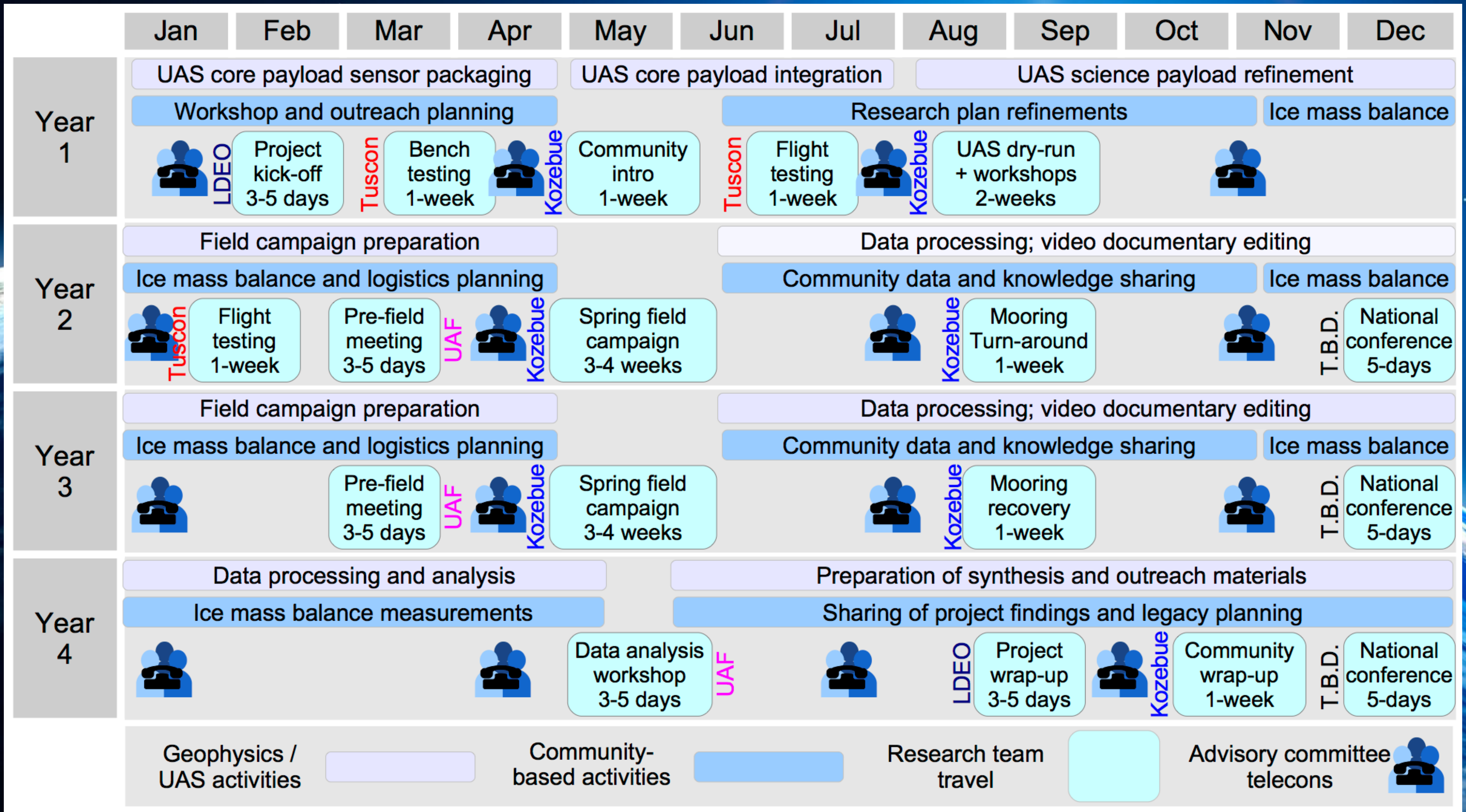
Project Objectives

Science	**Improve understanding of the mechanisms, impacts, and implications of sea ice retreat in the Arctic for the global science community and local stakeholders**
Community	Develop partnerships between scientists and local residents to increase the capacity of local communities to address their research needs
Legacy	Document the progress of the project as a potential model for future community-based collaborative science endeavors in the Arctic

Project Overview



Project Timeline



Work Plan

Year 1

- Develop a joint research plan with the Kotzebue indigenous community to incorporate their concerns into the scientific objectives
- Integrate instruments into drones with test flights

Years 2-3

- 3-4 week field campaign each year during sea ice melt to collect data
- Community data and knowledge sharing
- Video ethnography

Year 4

- Data analysis, sharing and dissemination
- Video documentary provided to community and distributed more broadly

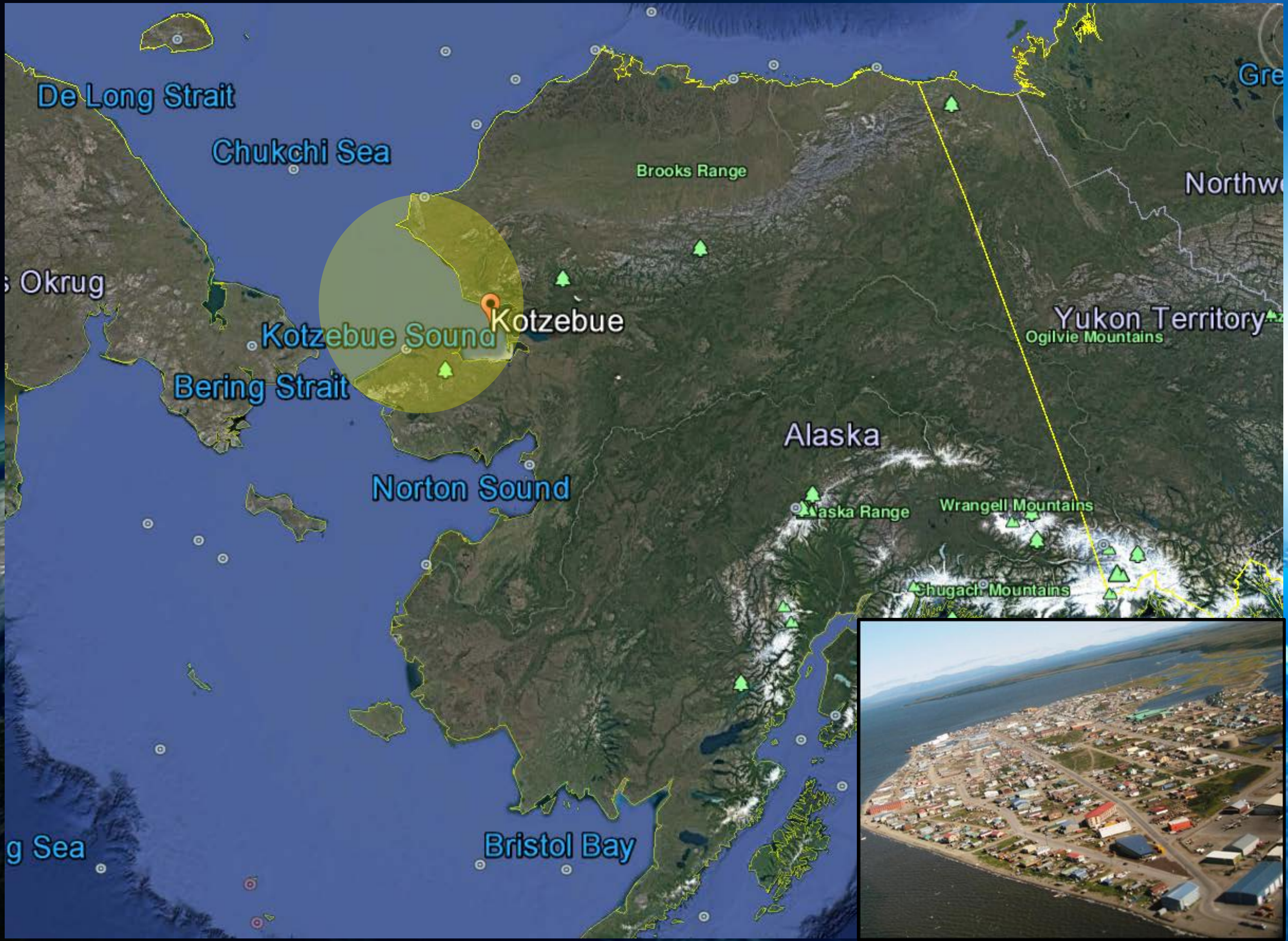

LATITUDE
HQ 90 SYSTEM

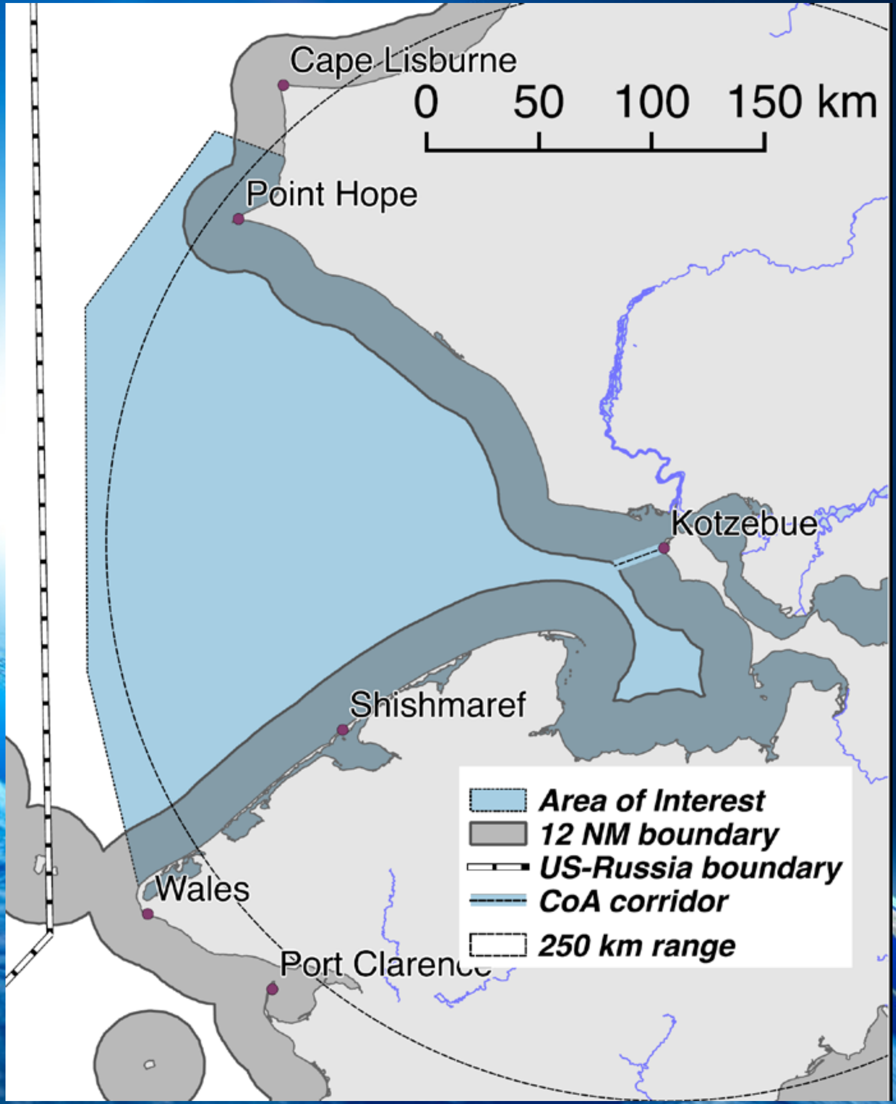
UAS Payloads

Table 1: Implemented science payloads and applications	
Payload	Sensing technologies
VIS-TIR*	High-resolution broadband visible (400-700 nm) imager, uncooled microbolometer (8-14 μm) imager sensitive to 0.05°C for skin sea surface temperature (SST) mapping, whitecapping, and other upper ocean processes.
Hi-TIR*	Cooled infrared (7.7 – 9.5 μm) imager sensitive to 0.02°C for skin SST mapping, whitecapping, and other upper ocean processes.
HYP-VNIR*	Hyperspectral visible (300-1000 nm) imaging spectrometer with better than 3 nm spectral resolution for spectral radiance measurements of the upper-ocean to determine ocean color and biogeochemical mapping. Upward-looking narrow FOV spectrometer provides measurements for estimates of spectral albedo of varying surfaces including ocean.
HYP-NIR*	Hyperspectral near-infrared (900-1700 nm) imaging spectrometer with better than 3 nm spectral resolution for spectral radiance measurements of the near-surface ocean to determine ocean color and biogeochemical mapping.
Li-MET	LiDAR for wave height and surface roughness; fast response 3D wind speed and direction (100 Hz), fast response temperature (50 Hz), fast response relative humidity (100 Hz) for estimating momentum, latent heat and sensible heat turbulent fluxes.
RAD*	Upward- and downward-looking pryanometer (broadband solar 285-3000 nm) and pyrgeometer (broadband longwave; 4.5-40 μm) to measure full hemispheric irradiance to understand the surface energy budget and map albedo of varying surfaces including the ocean. High-resolution broadband visible (400-700 nm) imaging is used to map whitecapping and other upper ocean processes.
DDμD*	Drone-Deployed Micro-Drifters with launcher for in-flight ejection of up to four micro-dropsonde packages. The DDμD measures temperature, pressure, and relative humidity as it descends through the atmosphere. Once it lands on the ocean's surface, it deploys a string of sensors that measures temperature and salinity of the upper 2-3 meters of the ocean at fifteen minute intervals for up to two weeks as a buoy. The ocean sensors on the DDμD collect and store data and then transmit the data back to the UAS on subsequent flights from up to 10 miles away.
***also included upward- and downward-looking pyrometers (8-14 μm) to measure narrow field-of-view (FOV) skin SST and ice-surface temperature.**	

Sea Ice Radar Development – Built on experience from IcePOD at LDEO

Village of Kotzebue



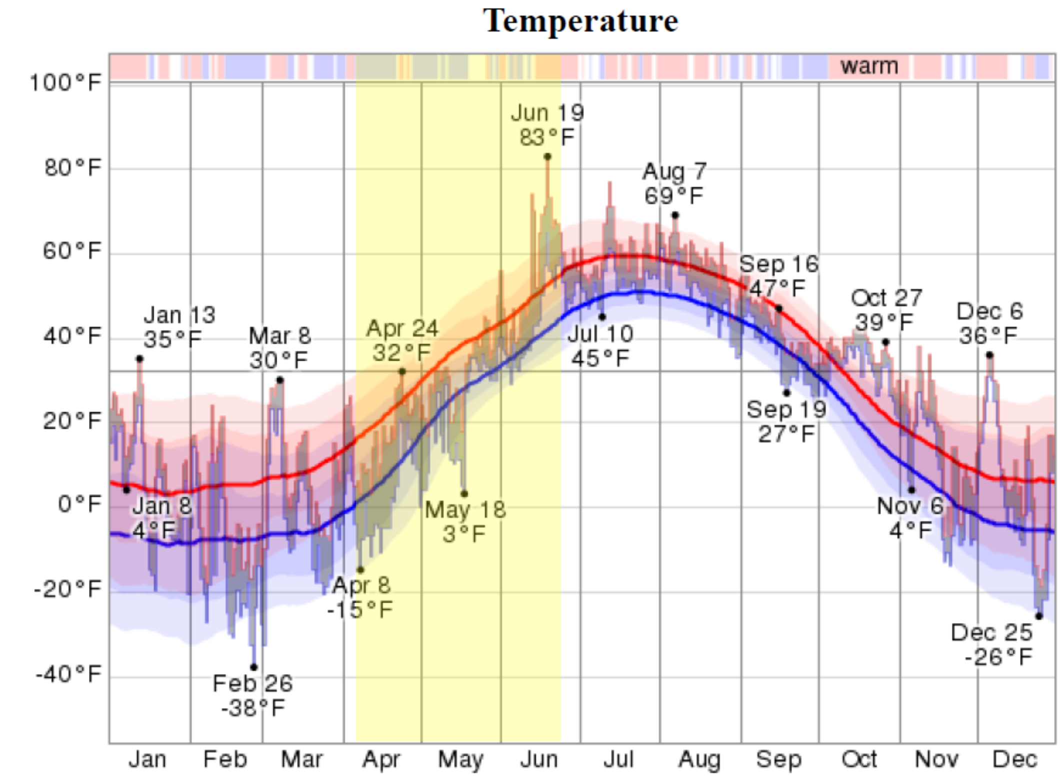


Indigenous knowledge

Indigenous knowledge is “a systematic way of thinking applied to phenomena across biological, physical, cultural and spiritual systems. It includes insights based on evidence acquired through direct and long-term experiences and extensive and multigenerational observations, lessons and skills. It has developed over millennia and is still developing in a living process, including knowledge acquired today and in the future, and it is passed on from generation to generation” (ICC Alaska 2015).

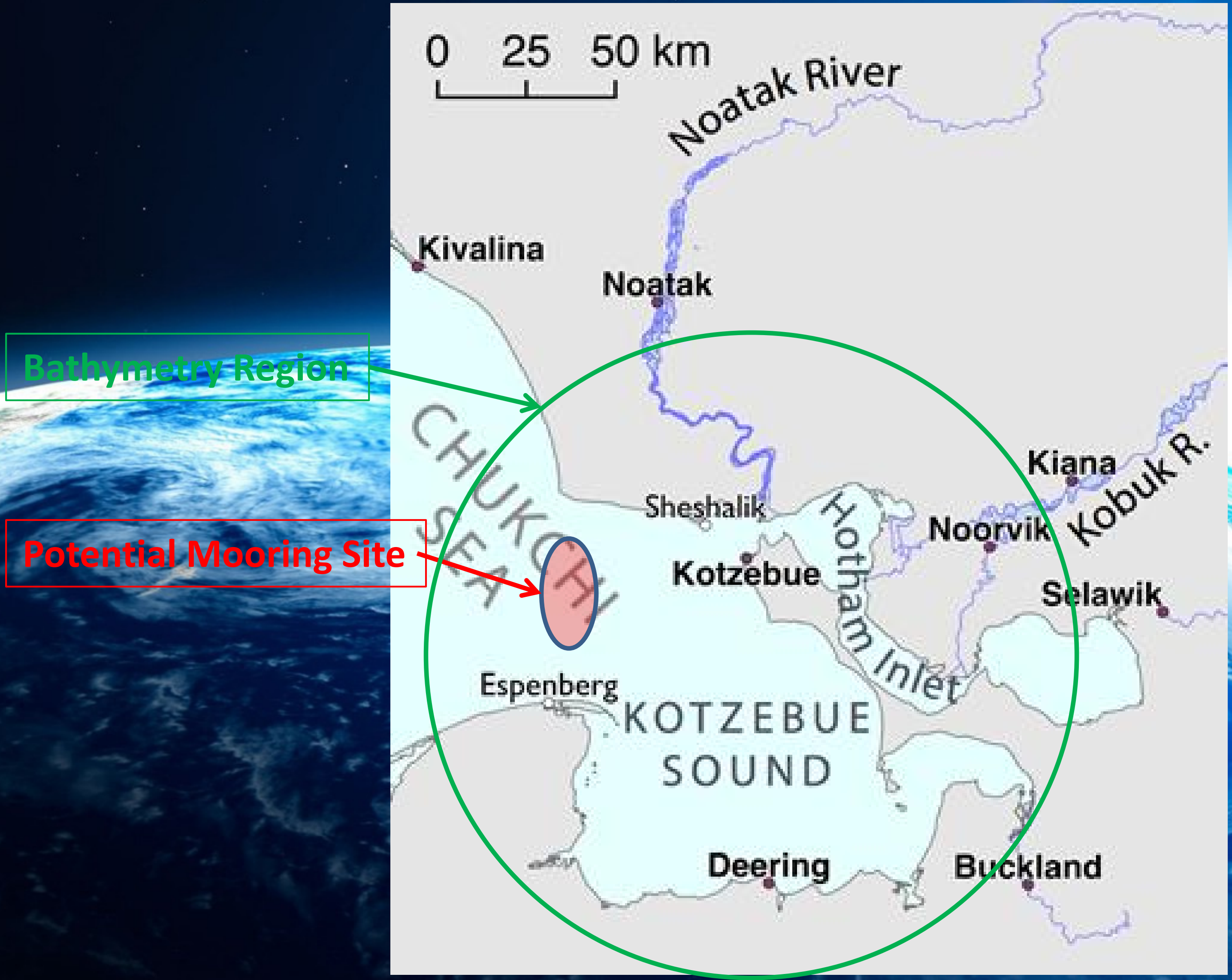
Kotzebue Temperatures

UAS: Maximum Temperature 100.4F and Minimum Temperature -4F

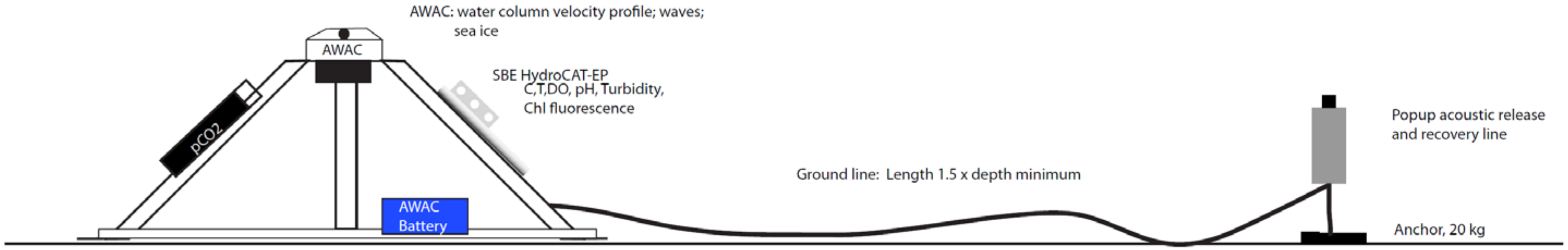


The daily low (blue) and high (red) temperature during 2013 with the area between them shaded gray and superimposed over the corresponding averages (thick lines), and with percentile bands (inner band from 25th to 75th percentile, outer band from 10th to 90th percentile). The bar at the top of the graph is red where both the daily high and low are above average, blue where they are both below average, and white otherwise.

Mooring Location



Mooring



Notes:

AWAC can be gimbal mounted. A ballast weight would have to be added beneath the AWAC to provide righting moment
Anchor can be recovered with the popup release line.
Ground line is ideally plastic-covered steel mooring wired, 3/16", in case popup buoy fails and the ground line must be grappled.
Assumes water depth not to exceed 20 m
Anchor weight is approximate pending final design

White House Announcement

THE WHITE HOUSE
Office of the Press Secretary

FOR IMMEDIATE RELEASE
December 9, 2016

FACT SHEET: White House Announces Actions to Protect Natural and Cultural Resources in Alaskan Arctic Ocean

Since taking office, President Obama has worked to protect the Arctic's natural and cultural resources and the communities that rely upon them through the use of science-based decision making, enhanced coordination of Federal Arctic management, efforts to combat illegal fishing, and revitalization of the process for establishing new marine sanctuaries. Building on this effort, today, President Obama is announcing new steps to enhance the resilience of the Alaskan Arctic environment and the sustainability of Alaskan native communities with the creation of the Northern Bering Sea Climate Resilience Area.

In addition to today's protections, the Obama Adminis
approximately $30 million in philanthropic commitmen
Alaska and Canada. These projects include investment
related to shipping, ecosystem science, community and

- Today, the **Gordon and Betty Moore Foundation** is announcing a $3.7 million grant to support research that couples state-of-the-art geophysical observations from unmanned aerial systems with a community-engaged research approach to bridge scientific and indigenous understanding of sea ice change in the Alaskan Arctic. Led by the University of Alaska Fairbanks, Columbia University, and Kotzebue residents, the project will research changing patterns of Arctic ice and other physical characteristics in Kotzebue Sound and the Chukchi Sea, using a combination of traditional knowledge and sensing technologies in modules carried by drones. From the beginning of the work - including development of the research design - the project will involve local experts who have sea ice experience and other environmental knowledge.

QUESTIONS?